Color Image Quality Prediction Models for Color Hard Copy

Toshihiko Inagaki, Takashi Miyagi, Shinji Sasahara,
Tomoyasu Matsuzaki and Toshie Gotoh
Corporate Research Lab., Imaging Science & Technology Lab.,
Fuji Xerox Co., Ltd., Ebina, Kanagawa, Japan

Abstract

Color image quality prediction models for two typical documents used as input for color copying machines have been developed to relate subjective image quality ratings to physical image quality metrics using stepwise multiple regression analysis. The typical documents consist of colored map and portrait images. The models were consistent with technical knowledge and achieved high correlation between predicted ratings and measured subjective image quality ratings. By utilizing the models, subjective color image quality can be measured by instrumental measurements, and also color imaging system of preferred image quality can be designed by physical image quality metrics, and this leads to effective image quality design.

1. Introduction

The image quality of color copying machines has been improved year after year by applying digital technology and newly developed materials or subsystems. And the image quality design technology for digital color copying machines was necessary to develop improved image quality copying machines.

The image quality is usually judged by subjective evaluation such as perception or preference. The subjective evaluation fluctuates by the experience of the observer, the type of the image or document, or the purpose to use the copy. And the subjective quality responses of many observers to the same copy are quantified to extract common judgment or statistical mean responses. However, this method requires many observers, so it is not practical.

On the other hand, the objective evaluation by physical measurements has good reproducibility, and decision or judgment is easier because of the numerical expression. This makes it easier to evaluate image quality by tone reproduction, spatial frequency characteristics, image noise and color reproduction. However following disapproval were reported to the objective evaluation. In the case of spatial frequency characteristics, sharpness is not influenced by the modulation transfer function (MTF) of higher frequency above 8 cycles/mm.[1] And in the case of color portrait photography, decreasing the MTF of magenta on the part of skin color makes preferable sharpness.[2] Also in the case of radiographic system, image processing to enhance the specific frequency causing greater image noisier, but makes it easier to carry out a diagnosis.[3] And correlation between physical measurements and subjective evaluation is necessary.

There are some reports on the correlation between subjective evaluation and physical measurements about black and white hard copies,[4,5] but there is few for color hard copies.[6]

This report shows a result of correlation study between physical measurements and preference ratings which is a statistical mean response of subjective evaluation.

2. The Development Method of Image Quality Prediction Model

As for the method of making preference ratings relating with psychological attributes, it is general to extract psychological attributes which control preference ratings by the SD (semantic differential) method or MDS (multiple dimensional scaling) method, to develop mathematical models relating psychological attributes with preference ratings, and to develop algorithms which predict each psychological attribute from physical measurements.

In this report, without extracting psychological attributes, these mathematical models of the relation between preference ratings (Q) and physical image quality metrics (P) were developed by the stepwise multiple regression analysis. Preference ratings measured by categorical rating method were used as the dependent variable, and all physical metrics and derivatives were assumed as the independent variables. The equation for these models was as follows:

$$Q = \Sigma w_j f(P_j) \tag{1}$$

where w_j was the weighting coefficient of physical image quality metric function $f(P_j)$ for preference ratings.

The function for metric transformation was decided by estimating transform function from the scatter diagram which showed the relation between each physical image quality metric and preference rating by using measured data.

3. Test Objects Generation

Test prints were generated by various color copying machines using some documents and a physical metric measurement test chart as inputs. Sample documents selected from original documents used in the market consisted of a map image printed by 12 special color inks, a portrait image, a business graphics and others.

68 test prints for each document were generated by 14 kinds of color copying machines and an offset printing machine. The test prints were made up of the best samples

in each copy mode and degraded image quality samples to expand the range of image quality metric value.

4. Psychological Scaling

Categorical rating method was used as the method of psychological scaling. In the categorical rating method, some categories were prepared, and observers evaluated each test print on the category scale. Seven categories shown in figure 1 were used to measure preference rating. The scale was an ordinal scale which presented the order of quality and was no guarantee of the same intervals. Supposing that the quality scale had the same intervals, mean opinion score (MOS) which presented the average of observers' categories on the category scale was calculated. And the MOS scale ranging from 1 to 7 was linearly transformed into preference rating scale ranging from 0 to 100.

The psychological scaling for each test print was carried out by 36 observers under the D50 illuminant.

5. Metrics Measurement

The test pattern for metrics measurement made by offset printing consisted of solid area and 9 variable coverage halftone patches of 175 lines/inch ranging from 5 to 85% of primary color (C,M,Y,K) and secondly color (R,G,B), halftone patches of skin color, green grass and blue sky, 10 variable optical contrast density neutral solid patches ranging from 0.1 to 1.7, vertical and horizontal direction 100, 300, and 500μm wide lines of primary and secondly color, 500μm wide line of variable density neutral color and vertical and horizontal contrast transfer function (CTF) measurement line space arrays containing 0.5 to 20 lp/mm frequencies.

Using copy samples reproduced by this test pattern, colorimetry, glossiness, graininess, contrast spectrum, line density, line width, edge width and edge RMS were measured.

In the case of colorimetry, spectral reflectance distributions were measured by CMS 500 spectrophotometer manufactured by Murakami Color Laboratory. The measurement geometry was 45/0 and black sheet was used as backing material. And using CIE illuminant D50 and the CIE 1931 2° standard colorimetric observer data, tristimulus values were calculated. From these values, CIE1976 L* , a*, b*, metric chroma (C*) and hue angle (H°) were calculated by equation (2) and (3).

$$C^* = (a^{*2} + b^{*2})^{1/2} \qquad (2)$$

$$H^\circ = \tan^{-1} (b^*/a^*) \qquad (3)$$

In the case of glossiness, 75° specular glossiness was measured by GM-26D gloss meter manufactured by Murakami Color Laboratory.

In the case of graininess, using ISO visual density distributions measured by scanning micro densitometer called as image quality meter (IQM)[7] manufactured by Fuji Xerox, the average wiener spectrum WS(u) was calculated. The measurement aperture size was 20 × 1000μm, the geometry was 45/0 and white sheet of 0.07 optical density was used as backing material. And graininess was calculated by equation (4).

$$\text{graininess} = \delta u \exp(-1.8D)\Sigma\sqrt{WS(u)}VTF(u) \qquad (4)$$

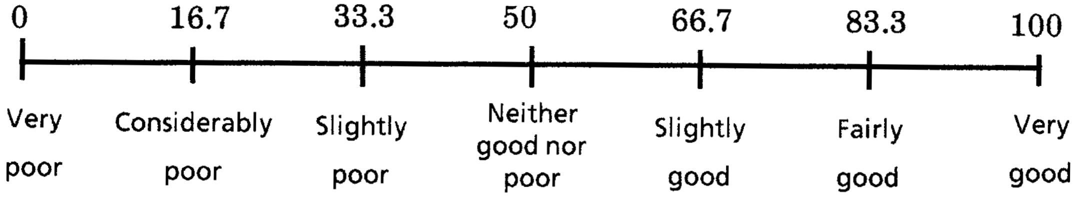


Figure 1. Seven step category scale and normalized preference rumors

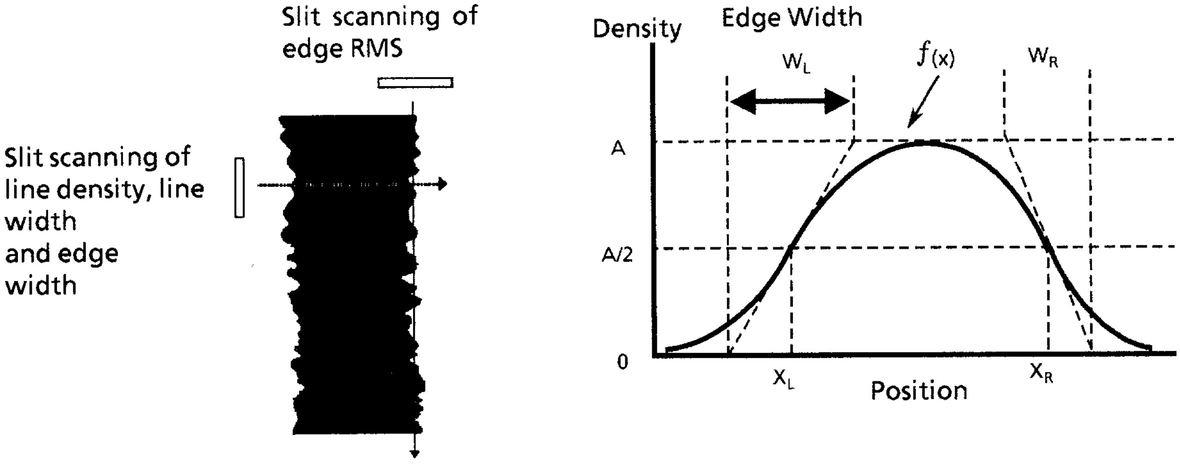


Figure 2. Scanning method and geometrical description of egde width

where VTF(u) is the visual transfer function and δu is the fundamental spatial frequency.

In the case of line density, line width, edge width and edge RMS, visual density distributions of each line image were measured by IQM with $10 \times 500\mu m$ aperture. The peak contrast density (line density), the distance between left and right position of 50 percent reflectance (line width) between maximum reflectance and minimmn reflectance, W_L and W_R (Edge width) obtained by fitting equation (5) to the measured line density profiles as shown in figure 2, and root mean square (edge RMS) of edge height were calculated.

$$f(x) = A/(\{1 + \exp[-4(x - X_L)/w_L]\}\{1 + \exp[4(x - X_R)/w_R]\}) \tag{5}$$

where x is the sampling position, A is the peak density. X_L and X_R are the positions where the density is A/2.

In the case of contrast spectrum, image area density (D_{line}) and none-image area density (D_{space}) were measured by IQM with $10 \times 500\mu m$ aperture and the contrast was calculated by equation (6).

$$\text{Contrast} = (10^{D^{line} - D^{space}} - 1) / (10^{D^{line} - D^{space}} + 1) \tag{6}$$

6. Color Image Quality Prediction Model

6.1 Image Quality Prediction Model For Color Portrait Image

A color image quality prediction model for portrait image was developed using stepwise multiple regression analysis. The regression analysis was done using subjective image quality ratings of portrait prints as a dependent variable and 799 kinds of image quality metrics as independent variables. The 799 metrics were converted from 315 kinds of fundamental image quality metrics which contained colorimetry (L*,C*,H°), glossiness and graininess of solid area and halftone patches and contrast spectrum of 8 targets ranging from 0.5 to 6.0 lp/mm. As a result, the following image quality prediction model was selected (Eq. 7)

The correlation coefficient between predicted ratings and observed ratings was 0.917. The model represents that the portrait image quality can be improved by increasing chroma of red solid area, decreasing the graininess of cyan 60% and skin color, adjusting the hue degree of neutral solid of 1.0 density to 305° which is bluish black and is 225° shifted from original point, adjusting chroma of blue 10% to 4.9 which is almost the same as original, adjusting chroma of blue 10% to 23.5 which is 4 point higher than original and adjusting chroma of cyan 70% to 36.8 which is almost the same as original.

6.2 Image Quality Prediction Model For Colored Map Image

A color image quality prediction model for colored map image was developed using stepwise multiple regression analysis. The regression analysis was done using subjective image quality ratings of colored map prints as a dependent variable and 1076 kinds of image quality metrics as independent variables. The 1076 metrics were converted from 400 kinds of fundamental image quality metrics which contained colorimetry (L*,C*,H°), glossiness and graininess of solid area and halftone patches, contrast spectrum of 8 targets ranging from 0.5 to 6.0 lp/mm, line density, width, edge RMS and edge width of 100, 300 and 500µm line of C,M,R,G,B and neutral. As a result, the following image quality prediction model was selected (Eq. 8).

The correlation coefficient between predicted ratings and observed ratings was 0.938. The model represents that the colored map image quality can be improved by decreasing the graininess of neutral solid of 0.3 density, adjusting the line width of blue 523µm line to 509µm, adjusting the hue degree of red 20% to 47.0° which is almost the same as original, adjusting chroma of red 5% to 3.0 which is almost the same as original, adjusting the line density of red 300µm line to 0.57 which is the almost same as original and

$$\begin{array}{llr}
 & & \underline{\text{F Value}} \\
\text{Portrait Image Quality Rating} = & 0.393 \times 10^{-8} \times (\text{C* of Red } 100\%)^{5.2} & 43.6 \\
 & +69.51 \times \text{EXP}(-0.125 \times \text{graininess of Cyan } 60\%) & 21.9 \\
 & -0.000173 \times (\text{H}^\circ \text{ of } 1.0 \text{ Neutral Solid} - 305.0)^2 & 14.3 \\
 & -0.409 \times (\text{C* of Blue } 10\% - 4.90)^2 & 13.5 \\
 & +47.7 \times \text{EXP}(-0.0766 \times \text{graininess of skin color}) & 11.5 \\
 & -0.0197 \times (\text{C* of Blue } 40\% - 23.5)^2 & 7.5 \\
 & -0.0452 \times (\text{C* of Cyan } 70\% - 36.8)^2 & 6.6 \\
 & -15.22 &
\end{array} \tag{7}$$

$$\begin{array}{llr}
 & & \underline{\text{F Value}} \\
\text{Map Image Quality Rating} = & +89.342 \times \exp(-0.055 \times \text{Graininess of D0.3 Neutral Solid}) & 63.69 \\
 & -0.0037321 \times (\text{Line Width of Blue } 500\mu - 509.0)^2 & 25.09 \\
 & -0.0048524 \times (\text{Hue degree of Red } 20\% - 47.0)^2 & 16.68 \\
 & -3.1084 \times (\text{C* of Red } 5\% - 3.0)^2 & 14.98 \\
 & -413.65 \times (\text{Line Density of Red } 300\mu - 0.60) & 14.17 \\
 & -46.377 \times (\text{Line Density of Green } 300\mu - 0.69) & 4.57 \\
 & +20.74 &
\end{array} \tag{8}$$

adJusting the line density of green 300μm line to 0.69 which is almost the same as original.

7. Application of Image Quality Prediction Model to Image Quality Design

The image quality prediction models were applied to establish image quality targets for newly developed digital color copying machine. The followings is an example.

A graph shown in figure 3 was made by plotting the preference rating of each color copying machine along the axis of ordinate and the commercial released date along the axis of abscissa, and a color image quality improvement trend line (A) of electrophotographic copying machines was estimated by linear regression. And an image quality benchmark line (B) was drawn by connecting the highest image quality machines and drawing parallel line to the trend line from the final highest image quality machine. Based on the image quality benchmark line, the image quality preference rating target of future color copying machine, for example at 1995, was set.

And each metric value was arranged to achieve the preference target using the prediction model. The initial value for each metric was set between that of the original

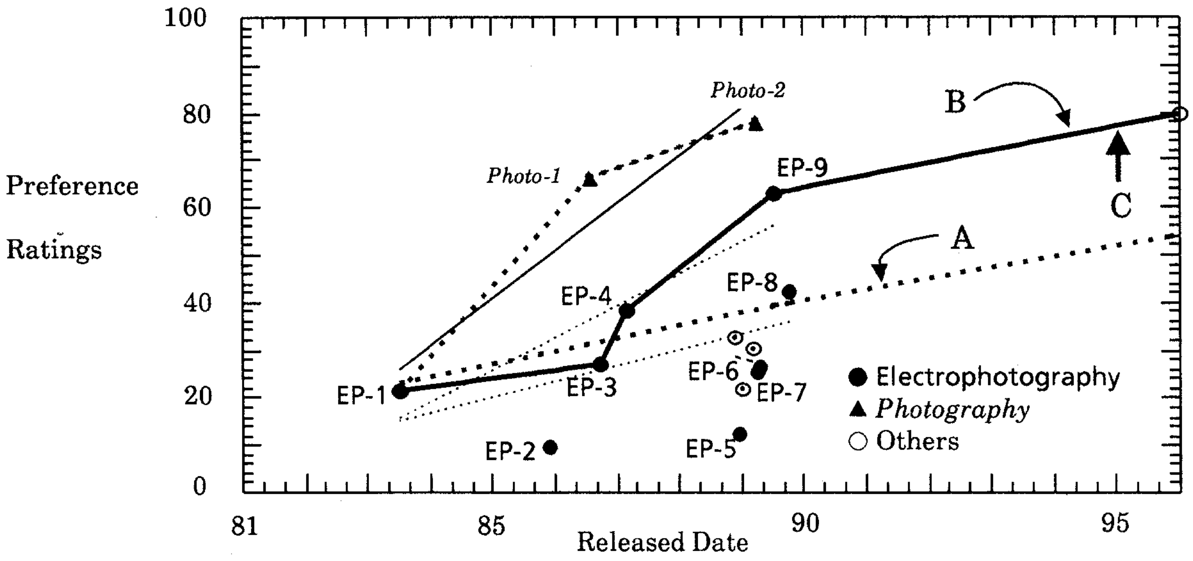
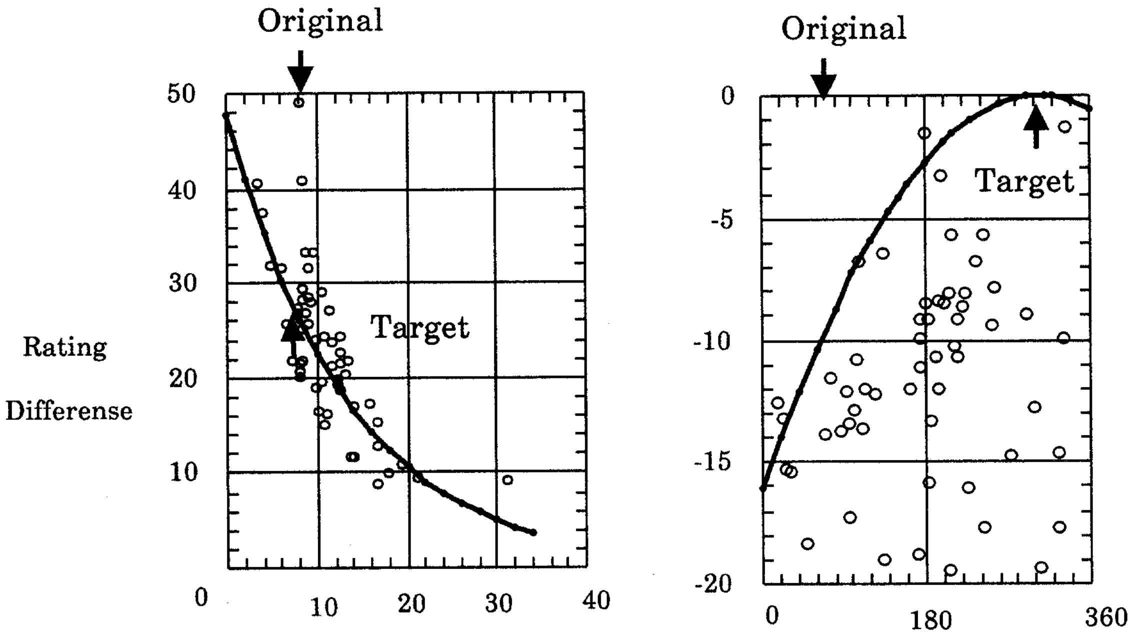


Figure 3. Color image quality benchmarking



a. graininess of skin color

b. H° of neutral solid of 1.0 density

Figure 4. Examples of metric target setting

and final benchmark machine. Figure 4 shows examples of target setting of graininess of skin color and hue degree of neutral solid of 1.0 density in the case of portrait image.

The comparison between the metric targets set by prediction models for all images and current technology level clarifies the most important metric to improve image quality, and this leads to effective image quality design.

8. Conclusion

Color image quality prediction models for portrait and map images were developed to relate subjective image quality ratings to physical image quality metrics using stepwise multiple regression analysis. The models were consistent with technical knowledge and achieve high correlation coefficients between predicted ratings and measured subjective image quality ratings. By utilizing the models, subjective color image quality can be measured by instrumental measurements, and also color imaging system of preferred image quality can be designed by physical image quality metrics, and this leads to effective image quality design.

9. References

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