# Development of a Method of Evaluating Uniformity Based on the Human Vision Property

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## Abstract

*Uniformity is an important quality factor of a hard-copy image and needs to be properly managed using a numerical index. We therefore developed a new method of evaluating quality. The evaluation method involves calculating the delta E profile using the color difference of the neighborhood to remove the effect of image noise. This calculation algorithm is based on a persons contrast detection mechanism. Furthermore, the maximum color difference is extracted by comparing profiles because a person evaluates the part having the worst uniformity part in multiple regions. Our method provides a numerical index that represents a subjective score of image uniformity. We expect to manage image quality using our method.*

## Introduction

Uniformity is one of the most important quality factors of hard copy. Image nonuniformity, including streaks, bands, and unevenness, occurs because of mechanical and other problems. Table  describes the widths of defects while Figure 1 shows examples of printed matter including nonuniformity. These defects affect adversely the commercial value of printing machines because they are noticeable. It is therefore necessary to evaluate image uniformity quantitatively. Two previous evaluation methods were proposed in 2000[1] and 2013[2]. The first method evaluates uniformity by analyzing the frequency characteristics of the image. The evaluation value is calculated from the frequency amplitude weighted by human sensitivity characteristics. Although this method is effective for evaluating samples that include repetitive streaks, it is not effective in the case of aperiodic streaks. The detection sensitivity is poor with respect to streaks and bands with low repetition. Meanwhile, the second method, which we previously proposed, evaluates uniformity using smoothing filters. We used filters of different size to detect image unevenness of various size. Initially, high contribution rates were obtained using this method. However, in repeated verification, we found that the accuracy of the method was insufficient for evaluating samples with a broken streak. The image is one-dimensionally averaged to calculate the reflectance profile. In the case that there is a broken streak, the nonuniformity component becomes small. The accuracies of the two previous methods are insufficient for evaluating the uniformity of printed materials. We propose a new evaluation method that solves the above problems in the present paper.

**Table 1. Widths of defects**

| | | | |
|---|---|---|---|
| Streaks | | width $<$ | about 5mm |
| Bands | about 5mm $\leq$ | width $\leq$ | about 50mm |
| Unevenness | about 50mm $>$ | width | |

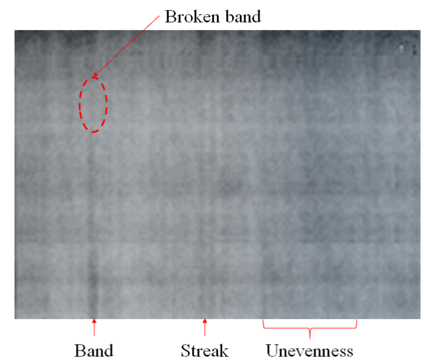


*Figure 1. Examples of defects*

## Methods

The purpose of the present study was to develop a method of evaluating uniformity that has high correlation with a subjective evaluation. We developed the method according to a reconsideration of the human visual property.

### *Human Vision Property*

We focus on the construction of the optic nerve. The optic nerve consists of several kinds of cells: retinal ganglion cells, amacrine cells, horizontal cells, bipolar cells, rod cells, and cone cells[3]. Among these cells, retinal ganglion cells have a contrast perception function similar to that of the Laplace of Gaussian (LOG) filter.[4] The LOG filter is a superposition of Laplacian and Gaussian filters. Figure 2 shows the shape of the LOG filter. The Laplacian filter behaves as a differential filter while the Gaussian filter behaves as a noise reduction filter. The evaluation method is based on these functions.

Moreover, we can recognize the existence of a streak or band even if part of the streak or band is lacking. In evaluating samples with a broken streak, we obtained the profile averaged over the whole image and the calculated streak components were weak. It is therefore necessary to reduce the effect of the broken streak.

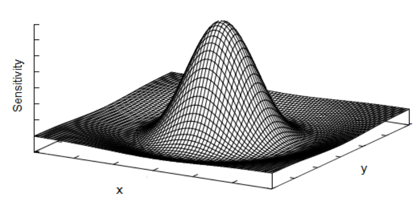


*Figure 2. Shape of the LOG filter*

## Algorithm

The method has two features that are based on the human vision property.

1. Calculation of the delta $E(\Delta E)$ profile using the color difference in the neighborhood
2. Extraction of the maximum color difference profile through comparison of color difference profiles

### Color difference in the neighborhood

The calculation of the color difference profile algorithm is shown below.

(1) Calculation of one-dimensional data by averaging the divided area along the streak direction
(2) Extraction of an interval of predetermined size
(3) Linear regression in this interval
(4) Calculation of delta $L*(\Delta L*)$, delta $a*(\Delta a*)$, and delta $b*(\Delta b*)$ at both ends of the line
(5) Shift of the interval to obtain $\Delta L*$, $\Delta a*$,and $\Delta b*$ profiles
(6) Calculation of the $\Delta E(\Delta E_{94})$[5] profile from the $\Delta L*$, $\Delta a*$, and $\Delta b*$ profiles

Figure 3 shows the above procedures. Noise needs to be removed from the profiles before we calculate $\Delta E$. We perform linear regression along the line to remove the noise, and calculate both ends of this line.

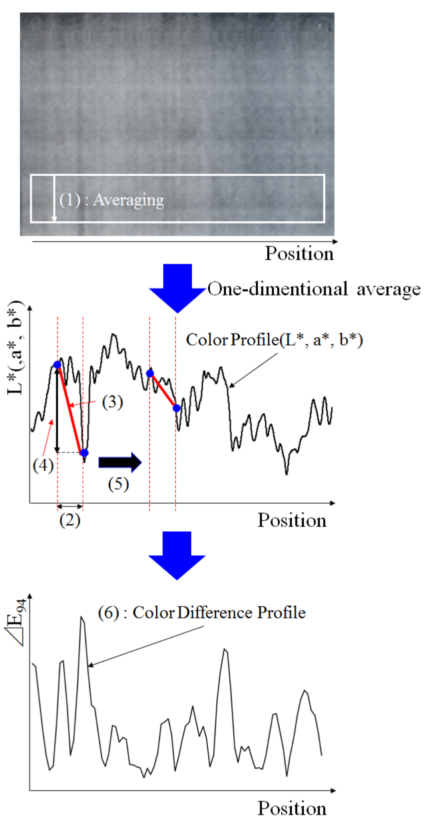


***Figure 3.*** *Calculation of the one-dimention L*a*b* color profile from the measurement image. The numbers in parentheses correspond to the procedure numbers.*

### Comparison of color difference profiles.

The details of the algorithm are presented below.

(i) Division of the image data into several regions
(ii) Getting one-dimension data by averaging the divided region along the streak direction
(iii) Application of the above procedures, from step (1) to (6), to each region, and getting the $\Delta E$ profile
(iv) Calculation of the maximum color difference profile ($E_i$) by comparing the $\Delta E$ profiles of all regions
(v) Extraction of nonuniformity components from the maximum color difference profile and taking their sum

Figure 4 shows the above procedures. Even if a part of a streak or band is broken, a person can recognize the existence of the streak or band. We therefore divide the scanned image into several regions, and calculate the maximum color difference profile from them. To obtain the nonuniformity components, a threshold is set for the maximum color difference profile, and parts exceeding the threshold are extracted. The evaluation value is expressed as equation (1), which represents the summation of extracted parts.

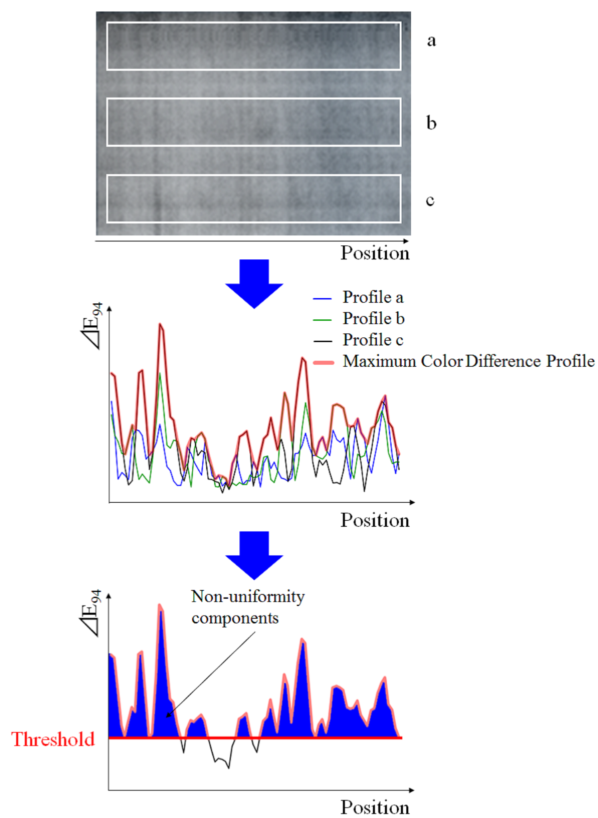


***Figure 4.*** *Calculation of the maximum color difference profile*

$$EvaluationValue = \frac{1}{n}\sum_{i}^{n} X_i \quad (1)$$

$$X_i = \begin{cases} E_i - Threshold & (E_i \geq Threshold) \\ 0 & (else) \end{cases}$$

To obtain the image data, we used an Offirio ES-10000G (Seiko Epson Corporation) scanner. The resolution was 300 dpi and the image size was A3 (297 mm × 210 mm).

## Verification

### Subjective Evaluation

We verified the accuracy of the proposed method with printed matter. Table 2 describes the experimental conditions. To obtain the subjective rank of the test samples, the samples were ranked with comparison scale samples. The scale samples were made from scanned image data that contained several types of defects and printed with a high-definition proofer. The scale samples were evaluated using Scheffè's method of paired comparisons[6] in advance. Two samples were chosen at random from six scale samples. Each participant compared these two samples and made a five-grade evaluation (1: much worse, 2: worse, 3: the same, 4: better, 5: much better) for all possible combinations of the samples. Figure 5 shows the method of subjective evaluating the scale samples. Table 3 gives the results of scale sample evaluation. These results were obtained with correspondence analysis[7]. Test samples were ranked in an 11-grade evaluation by participants (1: same as S1, 2: between S1 and S2, 3: same as S2, $\cdots$, 10: between S5 and S6, 11: same as S6), and the ranks of samples was associated with the scores of scale samples. Figure 6 shows the method of subjective evaluating test samples. The test sample score was the average of all participants' scores. Participants were 15 mechanical design engineers and image analysis engineers, aged 25 to 55 years and having normal color vision.

**Table 2. Experimental conditions**

| | |
|---|---|
| Test sample type | EP, IJ, OFFSET |
| Number of test samples | 69 |
| Test sample color | CMYKRGB(Halftone) |
| Scale sample type | EP(High-diffinition proofer) |
| Number of scale samples | 6 |
| Scale sample color | Black |
| Test & scale sample size | A3(297 mm×210 mm) |
| Lighting condition | D50, 1000 lx |
| Observation distance | Free |

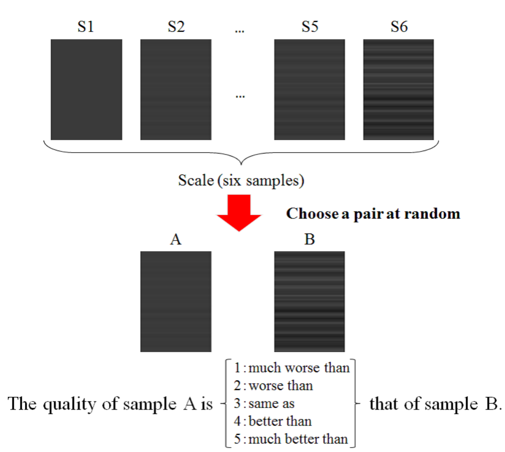


*Figure 5. Method of subjective evaluating scale samples*

**Table 3. Results of scale sample evaluation (scale sample scores)**

| Scale sample name | Score |
|---|---|
| S1 | -1.00 |
| S2 | -0.65 |
| S3 | -0.29 |
| S4 | 0.18 |
| S5 | 0.72 |
| S6 | 1.04 |

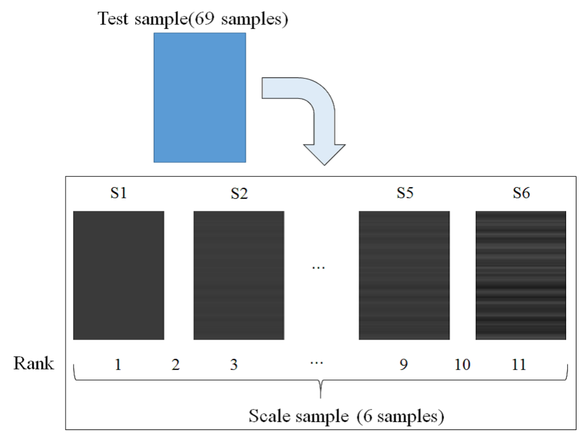


*Figure 6. Method of subjective evaluating test samples*

### Results

The correlation between the evaluation value and the subjective score is $R^2 = 0.81$(Figure 7). It is seen that the developed method well imitates the human vision property. Moreover, we compared the results of the developed method with those of a previous method [2]. The accuracy of the previous method is $R^2 = 0.39$(Figure 8). The comparison reveals that the developed method is more suitable for subjective evaluation.

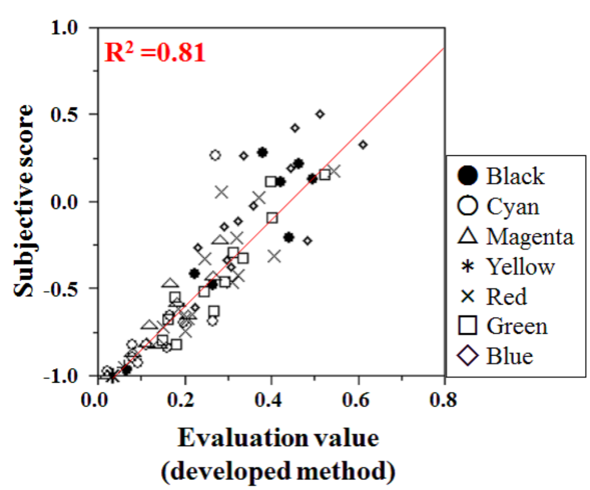


*Figure 7. Correlation between the evaluation value (obtained using the developed method) and the subjective score*

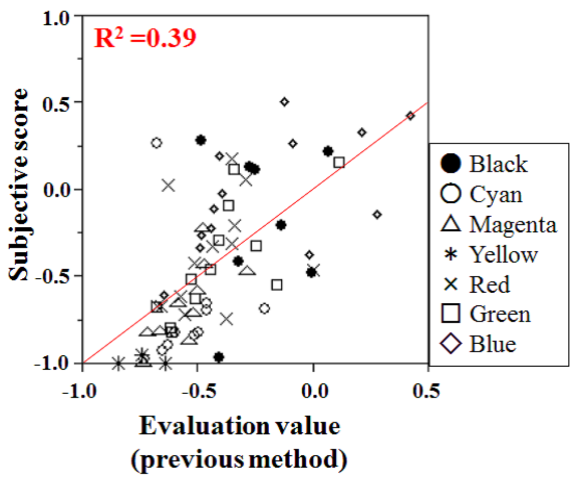


***Figure 8.*** *Correlation between the evaluation value (obtained using a previous method) and the subjective score*

## Conclusion

We developed a new method of evaluating image uniformity. This method is based on the human visual property. It involves calculation of the $\Delta E$ profile using the color difference in the neighborhood to remove the effect of image noise and extraction of the maximum color difference profile by comparing color difference profiles of multiple regions. High correlation($R^2 = 0.81$) was obtained between the evaluation value and subjective rank. In other words, the developed method provides a numerical index that represents the subjective score of image uniformity. Moreover, stronger correlation was achieved with the developed method than with the previous method($R^2 = 0.39$). We expect to manage image quality using the developed method.

## References


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## Author Biography

*Hideyuki Kihara received his Masters in mathematics from Waseda University in 2009. Since 2009, he has worked at Ricoh Company, Ltd. His work has focused on the image evaluation of hard copies. He is a member of the Imaging Society of Japan.*