

Contour Mapping of Readability of Hardcopies on the Plane of Optical Density: Characters and Background -A Guideline for Designing Electronic Paper-

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Abstract

Readability of hardcopies as determined by image density was evaluated for the purpose of clarifying the goal of readable Electronic Paper. Subjective evaluations were carried out on the readability of hardcopies whose characters and background has various combinations of optical densities. Evaluated results are summarized as a contour map of readability on the plane of optical density: characters and background. Two conventional ways of calculating contrast ratio (OD ratio and reflectance ratio) were evaluated using the mapped values. It is confirmed that equal contrast lines as determined by OD ratio show better agreement with the contour line of readability than those based on the reflectance ratio.

1. Introduction

It is not clear how to assess readability with regard to Electronic Paper.¹ The essential specifications for readability remain unclear. It will be useful, for designing reflection type Electronic Papers, to acquire accurate quantitative evaluations of hardcopy readability.⁴ This study aims to provide a quantitative evaluation of the dependence of readability on the optical density (OD) of characters and background, or their ratio (contrast).^{2,3}

In the field of display technology, the luminance ratio or reflectivity ratio of [White / Black] is used as an index of contrast. In the field of printing technology, on the other hand, OD ratio [Black / White] is used as an index of contrast. In general, we find far higher values of contrast in the specifications of display devices than those of printer devices, although we do not think of display images as being far more readable than printed material.

This disagreement arises from the difference in the definitions of the contrast as accepted in each field. It is only natural that we find smaller values of contrast ratio using

OD, because OD is defined as the logarithmic value of reflectance on paper: $OD = \log \{(\text{luminance of standard white plane}) / (\text{luminance of measured point})\}$. We expect better correspondence between readability and contrast value in the OD ratio than the simple luminance ratio or reflectance ratio, when we consider that human senses are generally logarithmic.

This study tries to elucidate the index that should be used in estimating the readability of reflective type media. Subjective evaluations on readability were carried out using printing samples that exhibited various combinations of OD (characters and background). Evaluated results were analyzed in a comparison of the two types of contrast ratio.

2. Experimental Method

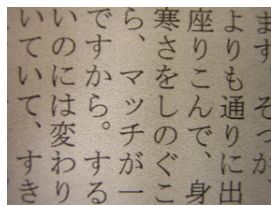
We prepared printing samples with various combinations of optical densities of characters and background. Subjects were asked to evaluate the readability of the samples and to make five groups of samples with similar readability.

Evaluations were carried out separately on each sample set of positive image (OD of characters > OD of background) and negative image (OD of characters < OD of background). Thirty six printed sample sheets were prepared for each of two character sizes: 11 point and 4 point. These sizes correspond to the typical font size used in newspapers and weekly comics. Experimental conditions are shown in Table 1. Typical 11 point samples are shown in Fig.1. Table 2 lists the directions given to the subjects.

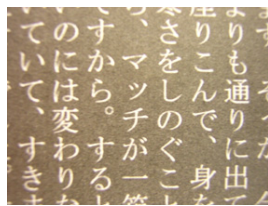
First, they were requested to arrange the 36 samples in order of their readability. They were then told to divide the 36 samples into 5 groups with similar readability. The subjects were free to decide the numbers of samples in each group. This freedom was intended to enhance the sensitivity of the subjects. Figure 2 shows a typical group produced by a subject.

Table 1. Experimental Conditions

	Items	Specs	
	place	noise attenuating room	
Environment	illuminance of the table	700 lux	
	light source	6000 K	
	evaluation time	no restriction	
	subjects	4 subjects	12 subjects
Printed sample	font size	4 point, 20 point	11 point
	paper	copy paper (whiteness 80%)	
	font	Ming-style	
	sentence direction	vertical writing	
	contents	novel	
	O.D. of character	O.D.=0.07~1.43	
	O.D. of background	O.D.=0.07~1.43	
	number of sheets	Posi:36sheets, Nega:36sheets	



Posi sample



Nega sample

Figure 1. Typical samples of 11 point

Table 2. Instructions for Subjects

Order to subjects
<ul style="list-style-type: none"> The sample with the worst readability must be grouped in Level 1 The sample with the best readability must be grouped in Level 5 All samples must be grouped in one of the 5 levels. Each group can have any number of samples. You may compare between any samples and may try any arrangement or grouping of samples.

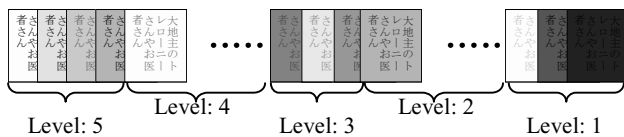


Figure 2. Grouping of 36 samples into 5 levels

3. Experimental Results

The final score of each sample was given as the average of all scores given by all subjects. Score 5 indicates the highest readability. Score 1 indicates the lowest readability.

Figure 3 shows an evaluated result for the 36+36 samples (positive and negative) in 11 point font. The diagonal lines in the bottom center of the graph represent equal lines of contrast =1.0. The positive image area and the negative image area are divided by the equal line.

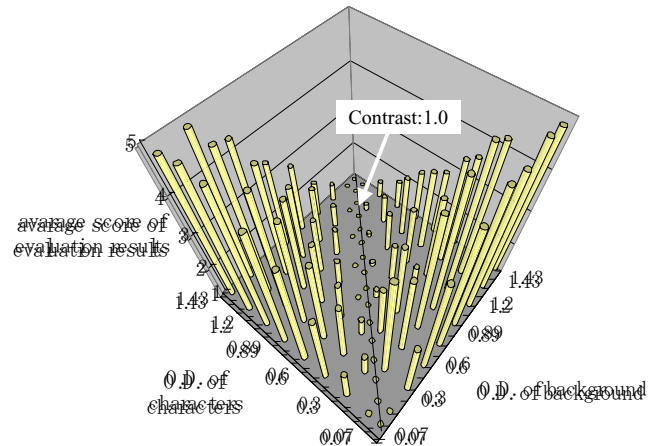


Figure 3. Results of subjective evaluation (font size : 11point)

These results were then processed by software to make contour lines of scores on the plane formed by the optical densities of characters and background. Figure 4 shows the processed result. Three contour lines of score 2, 3, and 4 were drawn in the positive and in the negative image area. As a result, four areas of averaged score (X) are indicated at each of the positive and negative region: $5 > X > 4$, $4 > X > 3$, $3 > X > 2$, and $2 > X > 1$ in each region.

Equal contrast lines using luminance ratio are also plotted in Fig. 4 for reference. Contrast ratio using luminance was calculated as follows:

$$\text{Luminance contrast: } C = 10^{(a-b)}$$

a: OD of black
b: OD of white

These equal contrast lines are straight and parallel.

Equal contrast lines using OD ratio are plotted in Fig. 5 on the same contour map as Fig. 4. Contrast ratio using OD was calculated as follows:

$$\text{OD contrast: } C = a/b$$

These kinds of equal contrast lines are straight and divergent.

It is shown, in Fig. 4 and Fig. 5, that the contour lines based on OD ratio are more similar to equal contrast lines than those based on luminance ratio.

Figure 6 shows contour mapping of evaluated results for the 4 point samples. More severe evaluation results are indicated by the contour lines for 4 point samples than that for 11 point samples.

Equal contrast lines using luminance ratio are also plotted in Fig. 6 for reference. Equal contrast lines using OD ratio are also plotted in Fig. 7 on the same contour map as Fig. 6. As a result, the similarity between the contour lines and the equal contrast lines based on OD ratio is increased; the similarity between the contour lines and the equal

contrast lines using luminance ratio is decreased on the other hand.

There is no major difference between mapped results for the positive and the negative samples: the counter lines are basically symmetric with respect to the equal contrast line of 1.0 for both 11 point and 4 point samples.

Checking the contour lines in detail indicates that the contour lines and the equal contrast lines of even OD ratio often cross each other. This fact shows that characters with the same contrast don't always show the same readability even using OD ratio. This kind of crossing is more distinctive for the 11 point samples.

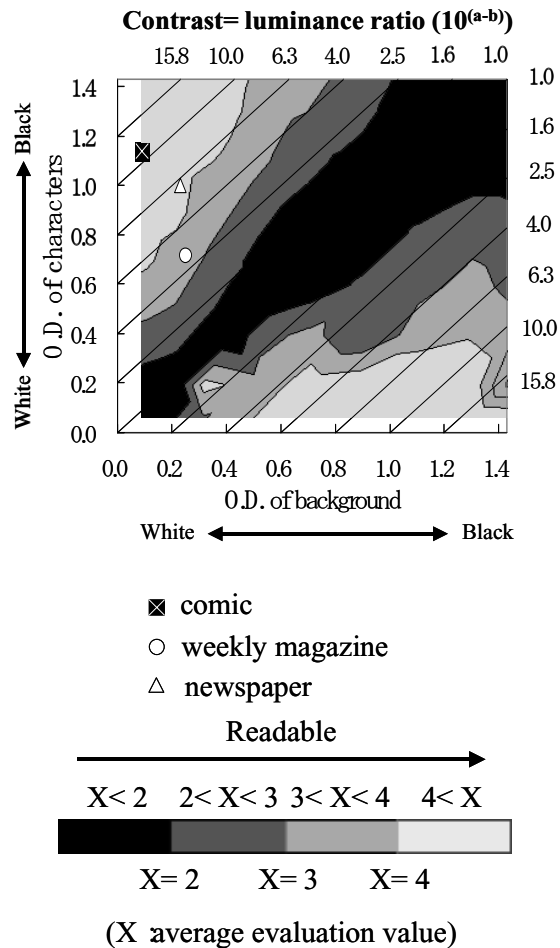


Figure 4. Mapping result of subjective evaluation (font size: 11 point)

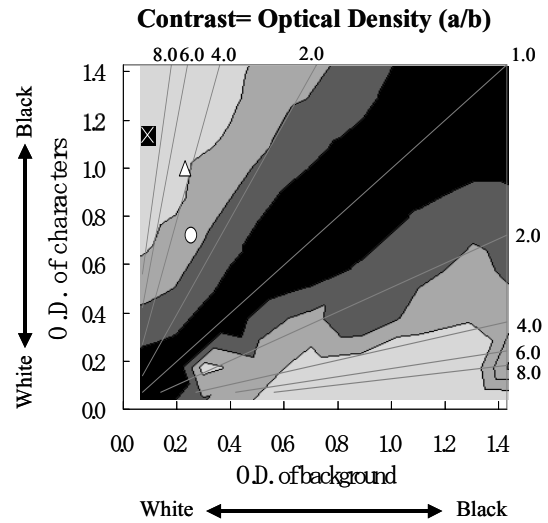


Figure 5. Mapping result of subjective evaluation (font size: 11 point)

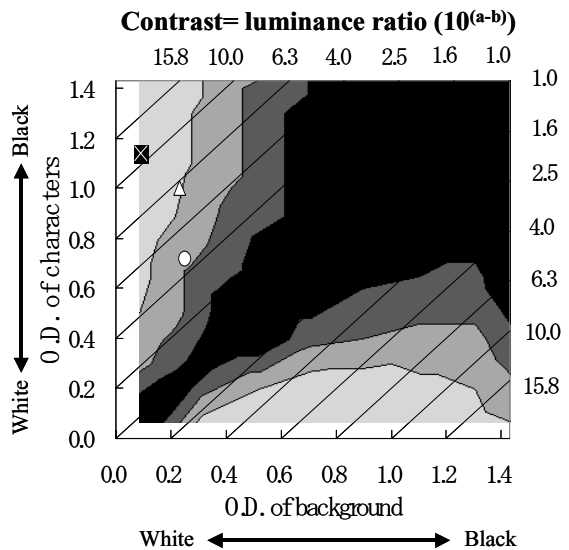


Figure 6. Mapping result of subjective evaluation (font size: 4 point)

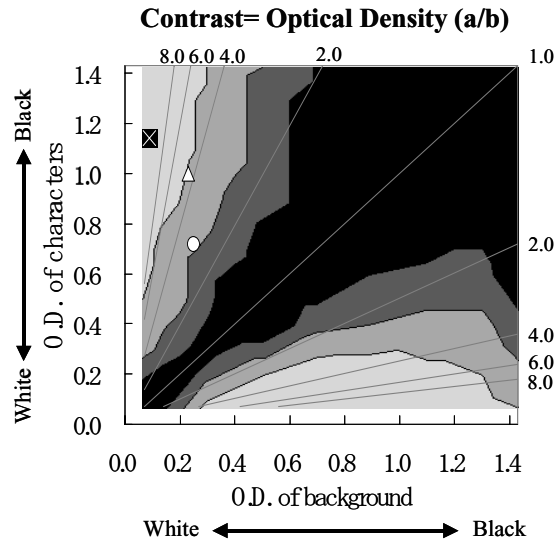


Figure 7. Mapping result of subjective evaluation (font size: 11 point)

4. Discussion

The above results show very clearly that contrast based on OD ratio is superior to that based on illuminance ratio in predicting the readability of character images. Equal lines of contrast based on OD ratio showed higher similarity to the contour lines of evaluation than the equal contrast lines derived from luminance ratio. This fact reconfirms that the contrast based on luminance ratio, which is generally used in the display field, doesn't match our impression of readability. The contrast based on OD ratio showed much better agreement with our impression of readability.

However, it should be noted that even the contrast based on OD ratio did not show enough matching with the contour lines of the evaluation results. The sets of OD values of character and background can predict readability more accurate on our map than the contrast ratios.

Typical examples of readable media are plotted in Figures 4 to 7. Selected examples are a newspaper (OD of character: 1.0, OD of background: 0.23, OD ratio = 4.3), a comic book (OD of character: 1.14, background: 0.09, OD

ratio = 12.7), and a weekly comic (OD of character: 0.72, OD of background: 0.25, OD ratio = 2.9). When we want to get a similar readability with one of these practical examples, its nearest contour line indicates other possible combinations of OD values for character and background. Thus, these experimental results can be utilized as a guideline for designing readable Electronic Paper.

5. Summary

1) We evaluated the readability of printed samples whose characters and background exhibited different sets of optical density combinations. The evaluated results were summarized as contour maps of readability on the optical density plane: characters and background.

2) Contrast ratios based on OD and luminance ratio were assessed in a comparison with the mapped readability scores. The contrast based on OD ratio was more accurate in estimating readability than that based on luminance ratio.

References

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Biography

Kazuyoshi Sakuragi was born in 1981. He received his B.S. degree in 2003 from Tokai University. He is expected to receive his M.S. degree from Graduate School of Tokai University in 2005. He is now engaged in a study of readability of hardcopy and Electronic paper.