Evaluation of Legibility

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Abstract

Text quality of images output from printers is very important in offices. We supposed that the text quality has two aspects, legibility and appearance, and they should be evaluated individually. However, while a large number of studies have been made on a text quality evaluation technique, there are few objective methods for practical purpose. This paper describes our investigation of how to evaluate legibility of images from printers objectively.

First, we supposed Chinese character (Kanji) reproductivity as an evaluation parameter of legibility. It is represented by a size and strokes of Chinese character being reproduced well enough. It is impossible to evaluate each of so many Chinese characters, therefore, this method is very effective for Chinese characters. Also, it is effective for the other characters, because Chinese characters have finer structures than the other characters in general.

The primary purpose of this paper is to require a quantitative evaluation technique of legibility. We brought an objective approach to the evaluation of legibility. We concentrated on line reproductivity and modulation transfer function (MTF). The reason we chose them is that the causes of deterioration of text are the breaks in lines and the poor resolution of lines in general. Line reproductivity is a parameter to show whether or not a line is reproduced well enough. We supposed an algorithm for measuring it in consideration of human visual characteristic. We studied the correlation between legibility and each of them. As a result, we found that we can predict legibility by better understanding and use of these two characteristics.

From the findings of these investigations, it is clear that we can evaluate the legibility of images output from printers quantitatively with a test target including plural patterns which vary in the line width or line width / line pitch essentially.

1. Introduction

Text quality is as important as ever, and has an influence upon total image quality as most documents still contain text. Further, users have required higher text quality for copiers or printers, as the volume of information in one document has been increasing in recent years (Figure 1). Therefore, a text quality evaluation technique is necessary for developing high quality copiers or printers. However to evaluate text quality is very difficult, because text quality has two aspects, legibility and appearance[1]. It is necessary to understand text quality in order to investigate both of them. Therefore, the study of an evaluation technique for them is vitally important to understand text quality well.

We began our study by considering legibility. This paper is intended as an investigation of a quantitative evaluation method for legibility, especially of Chinese character. To be more concrete, to begin with, we supposed Chinese character reproductivity as an evaluation parameter of legibility. Then, we supposed a quantitative evaluation technique of Chinese character reproductivity. Finally, we investigated the application of this method to printers.

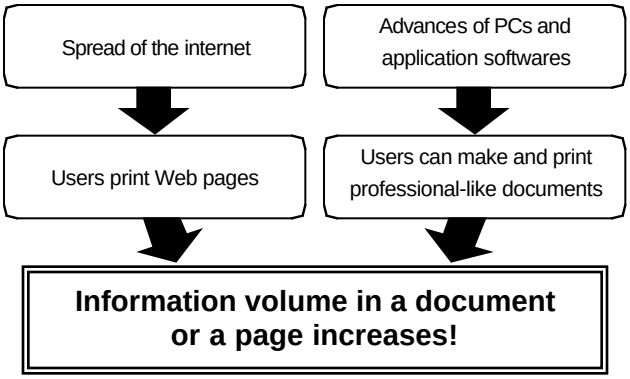

Figure 1. Background of our study

2. Basic idea

2-1. Chinese character reproductivity

Some people in Asia use Chinese characters. Therefore, we noted the Chinese characters' characteristics and we supposed "Chinese character reproductivity" as an evaluation parameter of legibility. It is impossible to evaluate each of so many Chinese characters. However, a Chinese character is composed of vertical lines and horizontal lines for the most part in general. Therefore, we supposed that Chinese character reproductivity as an evaluation parameter of legibility is obtained by measuring reproductivity of vertical lines, horizontal lines, squares and cross-lines for various line width and line pitch. The following equations (1) and (2) are obvious.

$$Line\ Width \propto Character\ Size \qquad (1)$$

$$\frac{Line\ Width}{Line\ Pitch} \propto Character\ Strokes \qquad (2)$$

It is possible to evaluate legibility two-dimensionally with a "Kanji simulator" (a test chart for Chinese character reproductivity). For example, "a character in 10 points is reproduced to 16 strokes." The features of Kanji simulator are as follows.

- Each block consists of six parts which correspond to different image character size. (One block is shown in Figure 2.)
- Each part consists of four elements, vertical lines, horizontal lines, squares and cross-lines. In each of these the line pitch is different, corresponding to character strokes.
- It consists of three different reflectance density blocks, 0.4, 0.9 and 1.5, to evaluate text both written in pencil (0.4) and in print (0.9 and 1.5).

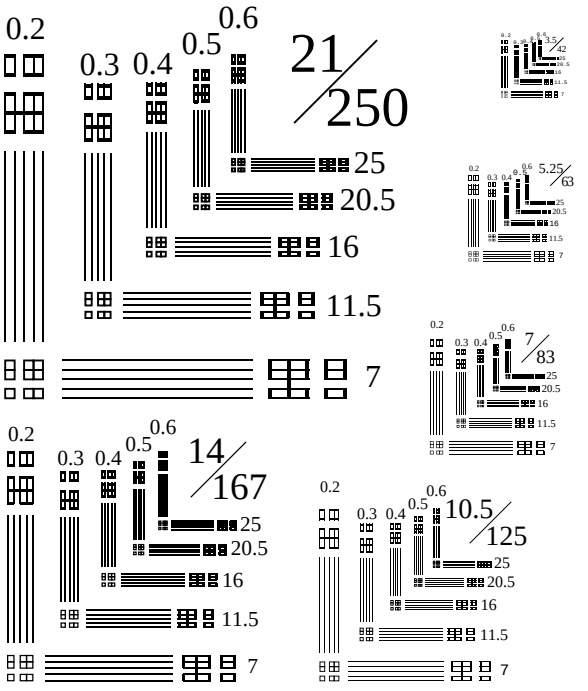

Figure 2. One block of "Kanji simulator" test chart

One diagram of the measurement result is shown in Figure 3. "○", "●", "□" and "+" indicate the reproduction of vertical lines, horizontal lines, squares and cross-lines respectively, and the shaded area indicates the complete reproduction. Using this, we can indicate that a character in 14 points reproduces to 25 strokes and a character in 7 points reproduces to 16 strokes easily. We previously reported that Chinese character reproductivity corresponds to legibility[1]. However, it is difficult to measure the reproductivity constantly, because an inspector observes with ×10 lupe and judges it subjectively. Therefore, a quantitative evaluation technique is required to resolve the problem.

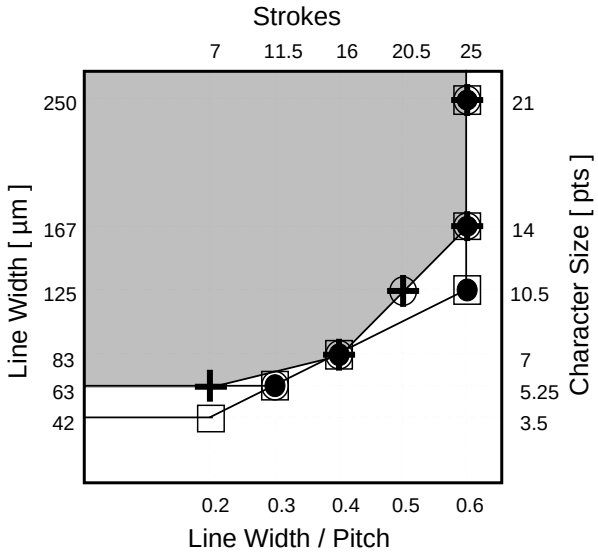

Figure 3. Diagram of Chinese character reproductivity

2-2. Objective approach to the evaluation of legibility

We previously reported that there is a correlation between Chinese character reproductivity and two parameters[2]. They are line reproductivity as a parameter that shows whether or not a line is reproduced well enough, and MTF as a parameter that shows whether or not lines are resolved well enough. Their measuring method will be explained in following paragraphs. It is important to appreciate that Chinese character reproductivity cannot be represented only by line reproductivity or MTF sufficiently, but it can be represented by both of them effectively. Still, these two alone are not sufficient conditions but are the necessary basics to represent Chinese character reproductivity. Because Chinese characters consist of complex patterns, such as cross-lines in addition to the two elements, vertical lines and horizontal lines.

Line reproductivity

Line reproductivity we supposed is an objective parameter to show whether or not a line is reproduced well enough. Here "well enough" means no visible breaks in the line when viewed at a predetermined distance. We supposed a simple algorithm for measuring line reproductivity in consideration of this. We calculated line reproductivity according to this algorithm. This measuring method consists of 4 steps;

1. With Fast Fourier Transform (FFT), reflectance image data of real space which are sampled with a drum-scanning type microdensitometer are transformed into its spatial frequency space.
2. The frequency space data are filtered by the transfer function of the visual system (VTF). VTF was calculated at a viewing distance of 200[mm] as expressed by equation (3)[3] in consideration of critical viewing.

$$VTF = 5.05\exp(-0.482u)\{1-\exp(-0.349u)\} \quad (3)$$

where : u = spatial frequency in cycles per mm

3. With inverse FFT, the filtered data are transformed into real space again.
4. The transformed data are binarized by a threshold.

In this method, we used two-dimensional FFT and inverse FFT to measure all sorts of defective lines, for example, jagged lines or blurred lines (Figure 4).

We adjusted the threshold to obtain the visually recognized line. We measured 200 lines, except lines which were broken or not clearly broken, and investigated the correlation between the results measured by plural threshold and the results of subjective evaluation. As a result, we found a suitable threshold by which the judgement as to whether or not a line is broken, corresponds in 170 out of 200 lines.

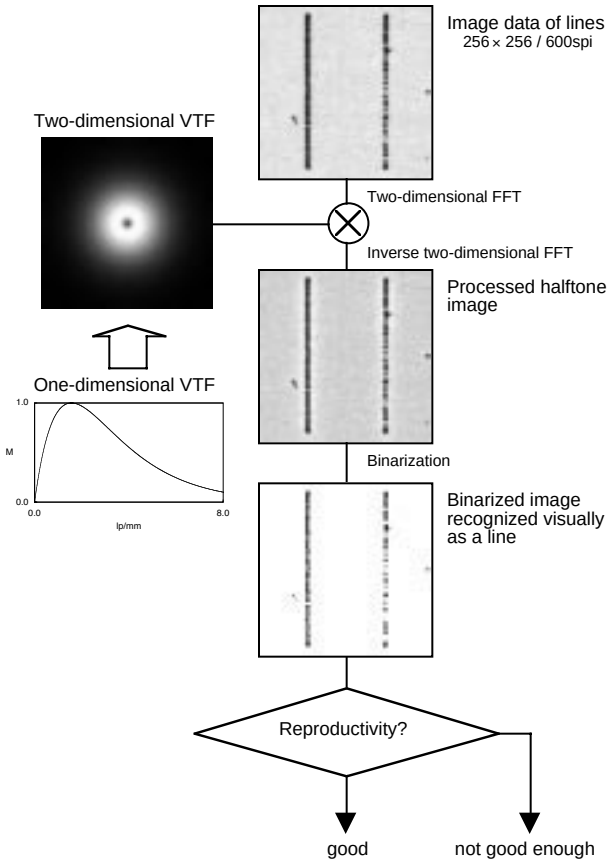

Figure 4. Proposed method to measure line reproductivity

Modulation Transfer Function (MTF)

We used rectangular-waves as input waveforms. MTF was calculated with the average and the amplitude of the output waveform. The average and amplitude are obtained from the Fourier transformed outputs. The black-and-white ratios of input waveforms were 2 : 8, 3 : 7, 4 : 6, 5 : 5 and 6 : 4. They were the same ratio as patterns in the Kanji simulator to investigate the correlation between text reproductivity and MTF. We compensated the measured value in consideration of the differences in the ratio of waveform.

3. Application to printers

3-1. Test target

Chinese character reproductivity can be represented by both of line reproductivity and MTF, as mentioned before. We supposed that this evaluation method could be applied to images output from printers. As a beginning, we prepared test targets to measure line reproductivity or MTF on the assumption to evaluate 600dpi-printer. The particulars of the test targets for printers are as follows.

Line width

In case of a test chart for copiers made with offset printing, the equation (1) holds good. The line widths of characters (Mincho font) in some different size in a test chart are shown in Table 1-(a). On the other hand, in case of printed characters, the equation (1) does not always hold good because the line width of bitmapped characters differ in printer's resolution. Table 1-(b) shows the case of 600dpi-printers. The line width of 7 points character is minimum size and the same as the line widths of 5.25 and 3.5 points characters.

Table 1. Relationship between character size and line width

Character size [pts]	Line width (a) Characters in test chart	(b) Printed characters (600dpi)
21	250 μm	4 / 600 inch
14	167 μm	3 / 600 inch
10.5	125 μm	2 / 600 inch
7	83 μm	1 / 600 inch
5.25	63 μm	
3.5	42 μm	

Line width / Line pitch

We investigated the relationship between strokes and ratio of line width / line pitch for 33 characters (Mincho font). Because Mincho font in the test target might be different from the character in the Kanji simulator. The measurement result and correspondence between the two parameters are shown in Figure 5 and Table 2. We prepared the rectangular-waveforms of test targets of which black-and-white ratios were approximately 2 : 8, 3 : 7 and 4 : 6 except some patterns of which black-and-white ratios were different from them. The reason why we did not prepare a rectangular-waveform of which black-and-white ratio is 5 : 5 was that we hardly use Chinese characters with 27 strokes. We compensated the black-and-white ratios of characters of which size is less than 5.25 points, because their line width are all the same and the equation (2) does not hold good in these cases.

We prepared test targets to measure line reproductivity and MTF based on Table 1-(b) and Table 3. Figure 6 and 7 indicate one block of the test targets.

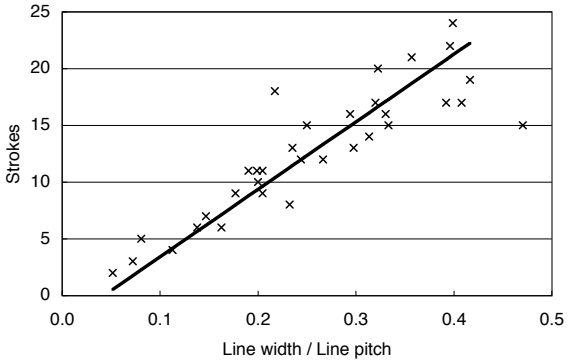

Figure 5. Measurement result of line width / line pitch and character strokes

Table 2. Correspondence between line width / line pitch and character strokes

Line width / Line pitch	Strokes
0.1	3
0.2	9
0.3	15
0.4	21
0.5	27

Table 3. Black-and-white ratios of rectangular-waveforms

Character size [pts]	Line width [1 / 600 inch] / Line pitch [1 / 600 inch]			
	3 strokes	9 strokes	15 strokes	21 strokes
21	4 / 40	4 / 20	4 / 13	4 / 10
14	3 / 30	3 / 15	3 / 10	3 / 7
10.5	2 / 20	2 / 10	2 / 7	2 / 5
7	1 / 10	1 / 5	1 / 3	-
5.25	1 / 8	1 / 4	-	1 / 2
3.5	1 / 5	-	-	-

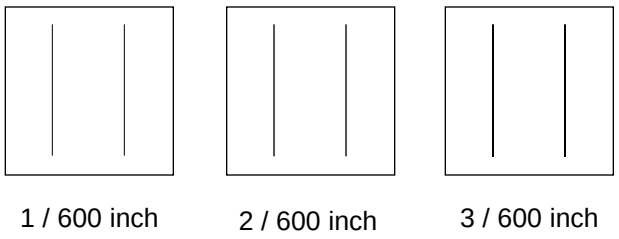

Figure 6. One block of test target to measure line reproductivity

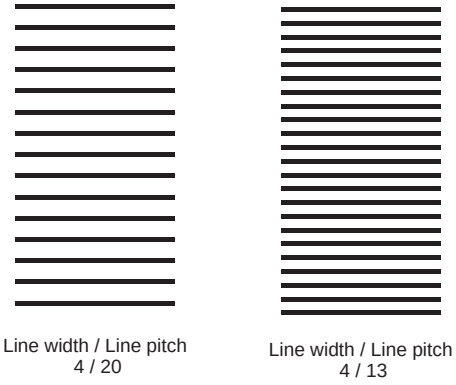

Figure 7. One part of test target to measure MTF

3-2. Experimental

We investigated the validity of the application. We measured some samples by the method mentioned above and evaluated them subjectively to compare the results. The printing condition for those samples is shown in Table 4. The two typical measurement results are shown in Figure 8. The graphs on the left indicate the subjective measurement results of legibility. Also, the graphs on the right indicate the objective measurement results of line reproductivity and MTF. To put it more precisely, the area where lines are reproduced and MTF is more than 0.2 are indicated. As the graphs indicate, in case of sample A, the area of subjective judgement corresponds well to the overlap of the area where lines are reproduced and the area where the value of MTF is more than 0.2. However, in case of sample B, there is not such correspondence. The reason for these different results is as follows. All images in sample A were not halftoned by the printer driver. Therefore we could predict Chinese character reproductivity using only test targets. On the other hand, in case of sample B, the method using test targets could not be applied to printed images, because all part of sample B were halftoned. These results led to the conclusion that the basic idea of the objective method is essentially effective, but the application to printers may not be practical.

Table 4. Printing condition

	Sample A	Sample B
Printer	600dpi-printer A Electrophotographic	600dpi-printer B Electrophotographic
Print Mode	Normal	Photo

4. Conclusions and Remarks

In conclusion:

(1) We can predict Chinese character reproductivity of copiers using line reproductivity and MTF effectively.

(2) The basic idea of the objective evaluation method can be applied to printed images essentially.

(3) However, it may not be a practical method, because it can not be applied to printed samples which are halftoned by printer drivers. If we use a PostScript file as the test target, we can solve such a problem.

We may note that the legibility of the alphabet is higher by one step than that of Chinese character from our experience.

We need to continue to study the practical evaluation method of printers. We must be aware of the importance of further work in the area of evaluation of color text, both legibility and appearance because there have been more opportunities to use color documents in recent years.

References

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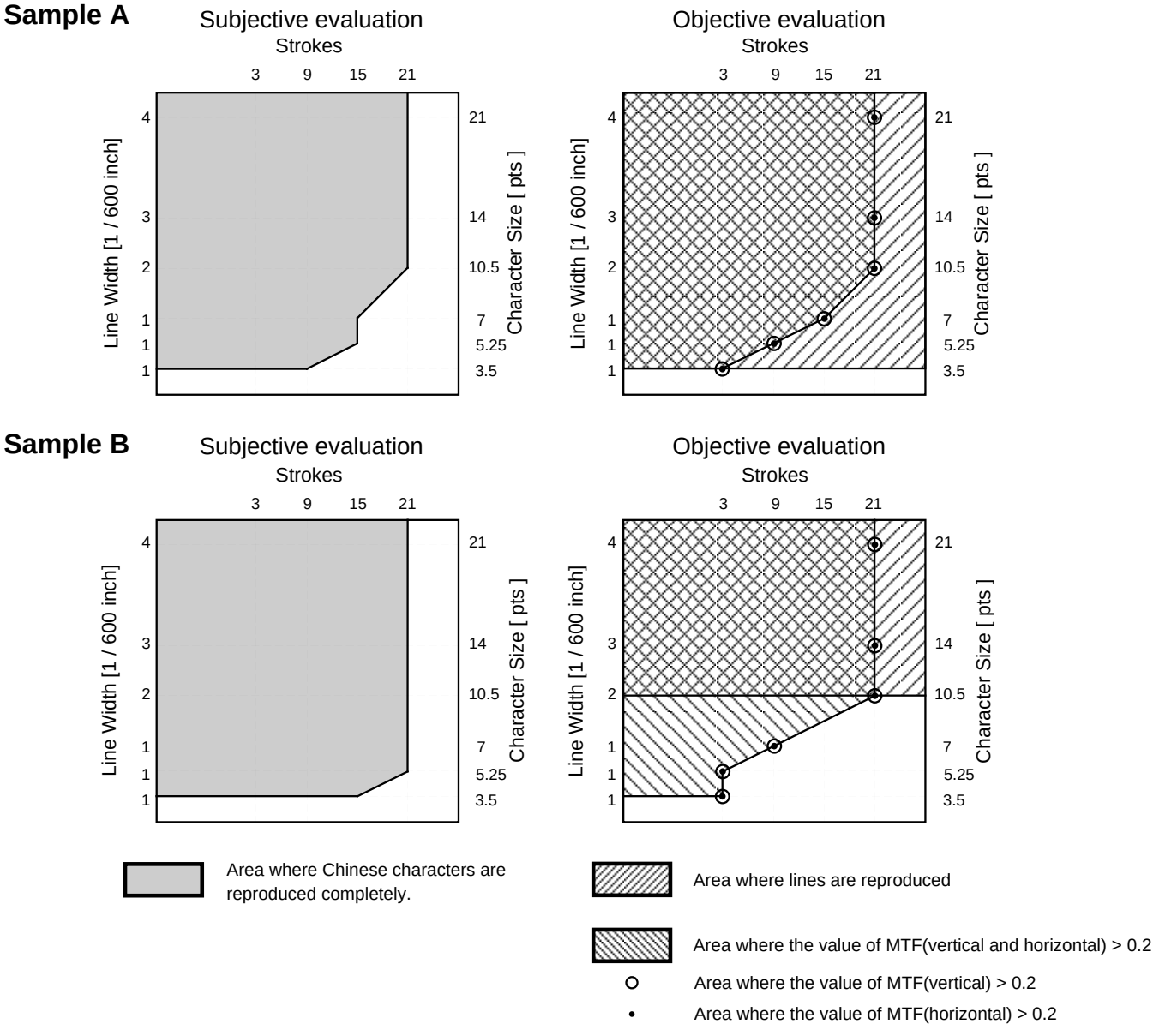

Figure 8. Relationship between Chinese character reproductivity, and line reproductivity and MTF