Study on High Quality Sensing Technique of Print Density Nonuniformity

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In the process of evaluating printing quality, detection of print density nonuniformity is one of the main examination items. However, our ability to do this has not progressed because contrast of objects is low, capturing steady image with a CCD camera is difficult, and calculating human perception is difficult. In this study we have paid attention to contrast differing with the wavelength of a light source and attempted to use selectively the wavelength emphasizing the print density nonuniformity. We have also paid attention to human visual sensitivity differing with the spatial size of an object and attempted to use the modulation transfer function (MTF) of visual perception to calculate the evaluation corresponding to human perception. In this way, it has been possible to obtain high-quality image data of print density nonuniformity and to calculate the human perception of it.

1. Introduction

Factors determining print quality are broadly divided into physical factors, such as resolution and misregistration of a print image at the time when colors are superposed, and sensual factors, such as sharpness and smoothness. There are a few cases that density nonuniformity, which is one of the sensual factors, causes defective prints. The measured values of physical density nonuniformity does not, however, necessarily correspond to sensual value of human perceptible nonuniformity, therefore it has been said that automated evaluation of density nonuniformity is difficult.

Density nonuniformity criteria for print quality inspection is so delicate and minute that even expert inspector cannot easily perceive it. It has been difficult to capture steady images of such nonuniformity by CCD cameras due to inadequate contrast.

Despite the application of automation in many other types of quality inspection, nonuniformity defect inspection has not been automated due to the above reasons. To automate such inspection through image processing requires to establish (1) high-contrast image input of minute density nonuniformity and (2) calculation method of evaluation values of density nonuniformity corresponding to sensual evaluation.

We studied input method of enhanced density nonuniformity images by selecting light source wavelengths, with glass printed matter for LCD color filters as an example. We also studied calculation method using human visual characteristics to realize evaluation values closer to visual inspection results.

2. Capturing of enhanced density nonuniformity images

The human perceives extremely minute differences as density nonuniformity. To capture stably such a density difference, contrast must be enhanced before image input. In this paper we study on enhancement of density nonuniformity contrast with a LCD color filter, produced by printing, as an example.

As shown in Fig. 1, the LCD color filter is usually printed with three types of ink — red, green, and blue — on a glass substrate with a vaporized black matrix to shade light. Fluctuation in ink film thickness results in fluctuation of quantity of transmitted light and is perceived as density nonuniformity.

The relationship between ink film thickness and transmitted light is expressed by equation (1).

\[ T = \frac{I}{I_0} = e^{-a t} \]

where,

- \( T \): Transmissivity of light
- \( I \): Quantity of transmitted light
- \( I_0 \): Quantity of incident light
- \( t \): Film thickness
- \( a \): Coefficient determined by ink and wavelength

From equation (1), transmissivity \( T \) changes to \( T^* \) when film thickness becomes \( a \)-fold.

Transmissivity of wavelength light with an 80% transmissivity in a certain film thickness, for example, is reduced to 64% if the film thickness is doubled, while transmissivity of wavelength light with a 40% transmissivity in a similar film thickness is reduced to 16%. The decrease in light quantity is 16% of incident light in the former case and is expanded to 24% in the latter, i.e., the quantity of transmitted light differs with the transmissivity of light despite the same film thickness change. Selectively using wavelengths widening the difference in light quantity enhances density nonuniformity contrast.

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Change in transmissivity $T$ in film thickness $t$ is expressed by equation (2) from equation (1).

\[
\frac{dT}{dt} = -a e^{-at} \\
\frac{\partial}{\partial a} \left( \frac{\partial T}{\partial t} \right) = e^{-at} (at-1)
\]

Change in transmissivity becomes maximum at $at=1$.

The transmissivity in this case is shown in equation (3), indicating that wavelength light with a transmissivity of 37% shows the maximum change in transmitted light quantity due to change in film thickness:

\[
T = \frac{1}{e} \approx 0.37
\]

Fig. 2 shows an example of the representative spectral transmissivity in standard film thickness of each ink. It is deduced from the above results that density nonuniformity contrast is enhanced by using wavelength light at about 590 nm for red and green ink and at 510 nm for blue ink. Fig. 3 shows spectral energy ratios of fluorescent light and a low-pressure natrium lamp. The low-pressure natrium lamp is a light source with light emission at 589 nm enhancing film thickness fluctuation in red and green ink. Fig. 4 shows the color filter images obtained by capturing with the above light sources. The natrium lamp produces sufficiently higher contrast by enhancing the density difference even if an ordinary camera is used, compared with a fluorescent lamp of white light. The wavelength enhancing fluctuation of ink film thickness differs with ink color. Such wavelength light sources can be produced by a wavelength band pass filter.

Fig. 2 Spectral transmissivity of red, green and blue ink
Spectral transmissivity at standard film thickness of representative red, green, and blue ink are shown.

Fig. 3 Spectral energy ratios of fluorescent light
and natrium lamp

Fig. 4 Difference of contrast with different light sources
(a) shows photograph under normal light source (fluorescent light), (b) photograph under light source with enhanced nonuniformity (natrium lamp).
3. Nonuniformity evaluation method

Density nonuniformity is caused by unevenness of image. A yardstick for expressing this unevenness is dispersion (standard deviation) in brightness level of the input image. Two types of unevenness exist; one can be perceived by human eye and the other can not. If evaluation value is determined based on physical unevenness, the result does not necessarily correspond to sensual evaluation.

Unevenness perceived by human must be evaluated to detect density nonuniformity.

3.1 Density nonuniformity and visual characteristics

Human visual perception has different perceptive sensitivity of density depending on spatial frequency. Fig. 5 shows the modulation transfer function (MTF) of visual perception, with spatial frequency (CPD: cycle/degree) on the X-axis and relative sensitivity on the Y-axis.

![Diagram of Modulation Transfer Function (MTF) of Human Visual Perception](image)

Fig. 5 Modulation Transfer Function (MTF) of human visual perception
(a) shows definition of angle of visibility, and (b) visual characteristic MTF.

Relative contrast sensitivity for spatial frequency of 3 CPD refers to sensitivity of density containing 3 cycles of sine-wave density patterns within the range of 1° visual angle. Human visual perception for density shows a bandpass filter characteristics with 3 CPD as the peak. (Fig. 5)

The physical size of each spatial frequency varies with the observation distance. Assuming 500 mm as the observation distance of normal print, the physical size of 3 CPD with the highest perceptive sensitivity becomes 2.6 mm/cycle.

3.2 Density nonuniformity evaluation method in consideration of visual characteristics

Information through the eye is modulated by visual transfer function and becomes a perceptive image. The transfer function in this case is the MTF of visual perception. Therefore, it is considered that input image can be transformed into an image close to the perceptive image ("perceived image") by two-dimensional Fourier transform of the input image and weighing on power spectrum of each spatial frequency depending on perceptive MTF, and inverse Fourier transform. (Fig. 6)

![Diagram of Flow of Calculation of Nonuniformity Evaluation](image)

Fig. 6 Flow of calculation of nonuniformity evaluation
At left is the flow of human visual perception processing and at right the calculation of density nonuniformity evaluation. An image equivalent to that perceived by the human eye is produced in the above processing.

Transformation into perceived image was executed by converting the object image into the spatial frequency observed from a distance of 500 mm and multiplying the power spectrum of each spatial frequency using the MTF approximate equation (3) and the following equation (4).

\[ H(f) = 0.31 + 0.69e^{-2.28f} \]  

where,

- \( H \): Weighing factor
- \( f \): Spatial frequency (CPD)

The above method weakens unevenness with low visual sensitivity, leaving only unevenness with high visual sensitivity. The unevenness of the perceived image (standard deviation of brightness level) is considered to be density nonuniformity perceived by the human.

A visual observation experiment verified that the calculation of evaluation values by above processing was equal to evaluation of perceived density nonuniformity. The experimen-

<table>
<thead>
<tr>
<th>Table 1 Condition and procedure of visual observation evaluation experiment</th>
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<tr>
<td>Persons tested</td>
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<tr>
<td>Observation distance</td>
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<td>Sample</td>
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| Procedures | Samples were carefully observed and divided into two groups:  
1. Samples with density nonuniformity perceived  
2. Samples with density nonuniformity not perceived |

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The results of visual observation evaluation experiment are shown in Table 1.

Sample images are inputted and the experimental results are reviewed by two methods.

1. The relation between brightness level standard deviation of the input image and the number of persons perceiving density nonuniformity is examined. [Fig. 7(a)]

2. The relation between brightness level standard deviation of the perceived image and the number of persons perceiving density nonuniformity is examined after the transformation of input image into perceived image. [Fig. 7(b)]

When the standard deviation of the input image is the evaluation value, it is found that even in the same evaluation value perception ratio of density nonuniformity disperses and the evaluation value do not agree with perception. On the other hand when the standard deviation of the perceived image is evaluation value, the perception of density nonuniformity starts at about 0.6 and almost all persons perceived density nonuniformity above 0.8. Thus, it is possible to detect only the density nonuniformity perceived by human using 0.6 as a threshold. The relation between evaluation value and the ratio of perceived density nonuniformity is stable, indicating that the standard deviation of the perceived image is effective as the evaluation.

4. Conclusion

A person viewing printed matter finds minute density fluctuation and perceives it as density nonuniformity. Steady image input and an appropriate density nonuniformity detection algorithm are required.

We verified that maximum density nonuniformity image contrast can be obtained by using selectively the light source wavelength irradiating the printed matter and the wavelength selection standard was obtained. Stabler input of density nonuniformity images became possible.

As for quantitative evaluation for print density nonuniformity corresponding to sensual evaluation, an effective measure close to visual evaluation was obtained by using the algorithm added with a human spatial visual sensitivity characteristic.

This study could contribute much to automating the density nonuniformity defect inspection of printed matter conventionally mainly relying on sensual evaluation based on visual observation.

References