

# Study on Visibility of Density Unevenness in Printed Images Affected by Characteristics in Input Images

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## Abstract

Visibility of density unevenness area appeared on printed images varies depending on some characteristics of input images. We focused on Saliency and Spatial frequency of tone distribution as those characteristics to clarify a mechanism for perceiving image noise.

In this study, we performed examinations for detecting density unevenness area. Shapes of the density unevenness are circle and belt-like. As results, we found that specific spatial frequency components in original tone distribution, which is similar to that of the density unevenness, correlated with the visibility of density unevenness. Trends between statistic values of saliency and visibility of density unevenness showed different depending on the polarity of density change. We could not clarify factors of this phenomenon. Finally, those statistic values of saliency which we studied were not proved as parameters affecting to visibility of density unevenness. All correlations for belt-like density unevenness were weaker than in case of circle. Some impacts of their size or continuity were supposed.

## Introduction

Many shapes of density unevenness can be appeared on printed images reproduced by electrophotography. In particular, belt-like density unevenness, one of those shapes, is prone to occur by fluctuation of printer parts or non-uniformity of charge on photo-receptor and so on. It is known that visibility of density unevenness as image noise in a printed image depends on contents of its background even if the level of the density unevenness is the same. If a correlation between visibility of density unevenness and characteristics of original images are clarified this correlation is useful for one of guidelines to set goals to develop production printing systems.

In most of previous studies, image quality was evaluated using output images including image noises. Our study leads to predicting possibility of standing out of density unevenness.

Effects of saliency on image quality assessment have often been discussed. Tong et al. reported results that salient region information improves image quality assessment [1]. On the other hand, spatial frequency of luminance distribution is known as a factor affecting to contrast detection thresholds [2]. We expected that visibility of density unevenness related to saliency or spatial frequency of luminance distribution on input images. In this study, we aimed to clarify correlations with these items to the visibility and to show effective conditions, in which the visibility of density unevenness becomes lower.

Assessment for belt-like density unevenness is important to predict failure in image engineering process. We assumed most of shapes can be described by combining plural circles of which luminance distribution is Gaussian distribution. Therefore, we selected density unevenness shaped circle and belt-like in this study.

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## Assumptions

### Definition of Density Unevenness

We focused on density unevenness changes only luminance because the contrast detecting thresholds for luminance contrast and color contrast are different [3].

Density unevenness was able to be defined as area which luminance distribution is different from that on original image data. Observers are possibly discriminate the difference when they know the original image. In our examination, to show test image to observer only once, experimenter showed images drawn the density unevenness on uniform density image previously, and make observers know its characteristics. We defined the area with same characteristics on test images was the density unevenness.

### Effects of Saliency

Saliency is property attracting observer's visual attention. There are 2 types of saliency called "bottom-up" or "top-down" [4]. Bottom-up type saliency is attributed to only characteristics of images. Top-down type saliency varies depending on purposes to observe the image. We had decided to discuss about Bottom up type saliency, and assumed that "saliency at a location close to the unevenness" or "level of saliency scattering" in input images correlate with visibility of the unevenness. For the former characteristic, we expected that a higher salient location in an image attracts attention so that an unevenness on the location can be easily found. Alternatively, we expected that Most of low salient locations are uniform in density so that an unevenness on the location pops out. For the latter characteristic, we thought that scattered saliency would facilitate attention scanning an entire image so that the unevenness can be found easier or cannot be focused on.

### Effects of Spatial Frequency

In our previous study, we found that the visibility of density unevenness lower when an input (original) image data includes spatial frequencies which were same as those of the unevenness. As mechanism of the phenomenon, we proposed the unevenness was not be discriminated when the gradation at a location of an unevenness part was the same as that of the unevenness. A display was used in the examination to show test images. We aimed to confirm reproducibility of that phenomenon on printed images in this study.

## Examination

We performed visual psychophysical examination for detecting a density unevenness area on each printed images. One density unevenness area was drawn as a target stimulus by experimenter on each input images.

### Conditions

The unevenness areas were circle or belt-like shape. The  $L^*$  ratio of output image drawn the unevenness to original image followed Gaussian distribution on the area of the unevenness (Fig. 1). The polarity of its luminance change was increment (white unevenness) or decrement (black unevenness). The viewing distance was 850 mm. The diameter of the circle unevenness's center area was  $1.0^\circ$  visual angle (14.1 mm), and the width of belt-like unevenness's center area was  $1.4^\circ$  visual angle (20.7 mm). Those center area means the amount of  $L^*$  change was more than 50% when it on center was defined as 100%.

The input images as background of the unevenness were natural images. Those image data were written in CMYK mode. CMY gradation without K arranged at the location where the unevenness drawn. K data in the input images were removed from the original photos previously.

The test images drawn the unevenness were printed by an inkjet system PX-H10000 (Seiko Epson) because it did not occur other similar unevenness attribute to the system. The size of whole test image is  $300 \times 300 \text{ mm}^2$ , 200 dpi. The test images are shown in a light booth. Fig. 2 shows the examples of test images.

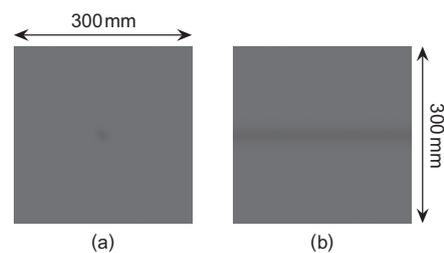


Fig. 1 The density unevenness images as target stimuli. (a) and (b) show circle and belt-like unevenness, respectively. Those  $L^*$  distribution on uniform density images are Gaussian distribution.

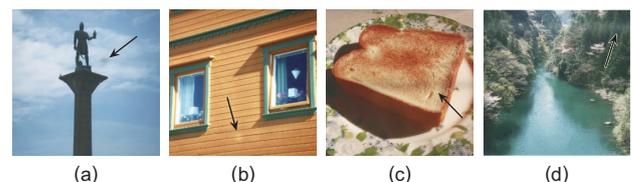


Fig. 2 The examples of test images. Each arrow marks the location of a density unevenness area. (a) Circle black unevenness. (b) Circle white unevenness. (c) Belt-like black unevenness. (d) Belt-like white unevenness.

## Tasks and Methods to Evaluate Visibility

7 subjects (2 20's females, 2 30's males, 1 40's female, 1 40's male and 1 60's male, all subject's visual accuracy is normal) tried task for detecting an unevenness area on each test images. First, an experimenter show a sample image drawn the unevenness on uniform density and give notice the subject shape, size and polarity of luminance change of the unevenness in test images. After 2 to 3 practices, a subject start trial. We used measuring reaction time (RT) and magnitude evaluation as methods to evaluate visibility of the unevenness

In the trial, an experimenter opens a cover in front of a test image and press key to start measuring reaction time (RT). A subject starts searching the unevenness in the image concurrently. The subject presses key to stop the time measurement when he or she finds the unevenness and the RT is recorded automatically. The experimenter confirms the subject which area was recognized as the unevenness after recording RT. If the answer is incorrect, or RT is more than 8s, the data is not used to analysis. That "8s" is approximate time which observer takes to view almost whole area of an image.

After measurement RT, the subject evaluates their impression for the unevenness on the scale of "Impression Ranks" shown on Table 1. No reference image is used to rank because the subject's answer is considered as pure reply without any adjustment. The subjects instructed to evaluate on the side of end users when they view photos ordered by themselves. Finally, only in case of the belt-like unevenness, the subject answers roughly which part is the most visible in the location of the belt because the belt-like unevenness stands out partly like Fig. 2 (c) in many cases.

The number of all test images and the trials were 144. We let subjects never view a same image to verify some effects of saliency.

Table 1 Impression Ranks.

Ranks	Criteria for judging
4	Highly visible (bad).
3	Visible (bad).
2	Visible (bad) a bit.
1	Discernible but not bad.
0	Not discernible as the unevenness.

## Analysis

### Luminance Ratio Occurred by the Unevenness

The luminance in this paper means that of light reflected on papers shown as test images. The luminance ratio of center and surround of each unevenness

areas were predicted nearly constant on image data. However, the ratio was changeable according to color profiling of printing system. Then we measured  $L^*$  profiles on printed test images and calculated them into luminance. We defined  $\Delta Y/Y$  as the luminance ratio of the unevenness.  $Y$  is an average luminance of area surrounding and close to the unevenness on each test images.  $\Delta Y$  is an averaged absolute value of luminance difference between center and surround of each unevenness areas.

The averaging range to calculate  $\Delta Y$  was defined as follows. In case of the circle unevenness, the averaging range to calculate center luminance of the unevenness was nearly equal to center area explained at the section of "Conditions". In case of the belt-like unevenness, when we calculated center luminance of it, the height of the averaging range was equal to center width of the unevenness, and the width was equal to that of the range when most subjects answered "visible particularly". the averaging range for surround areas was nearly equal to shadow areas in Fig. 3.

### Digitizing Saliency

We used the saliency map suggested by Itti et al. (1998) [5]. This describes bottom-up type saliency of arbitrary images. They recommended the size  $640 \times 480$ px as an input image and  $1/256$  of input size as created saliency map, and we followed that. The main points of algorithm to create the saliency map were as follows; 1) Resize the original image to  $640 \times 480$ px. 2) Separate original image data into future maps of colors, intensity and orientations. 3) Highlight areas with high contrast using Gaussian pyramids in each future maps. (It means highlighting attractive areas for human vision.) 4) Overlay all future maps as a saliency map on  $1/256$  size. On the saliency map, gradation data on high salient and low salient areas were calculated into light tone and dark tone, respectively.

We defined the gradation data on each pixels as S-value describing saliency level at the location. The average area for S-value was nearly equal to the shadow area in Fig. 3. This average was one of a parameter to verify the assumptions and describes saliency level on the location close to the unevenness. We also used summation and average deviation of S-value in each input images without the unevenness areas as parameters describing the level of scattering of high salient parts. According to the property of the saliency map, the summation of S-value increase when high salient parts scatters in the image.

We confirmed between each statistic values of S-value and RT or the impression rank.

### Spatial Frequency Analysis

We defined “F-value” as a parameter which described power level of spatial frequency of gradation distribution same to that of the unevenness. The procedure to calculate F-value was as follows.

First, the standard size was determined. In case of the circle unevenness, it was a square on a side which is equal to center area diameter explained as conditions. In case of the belt-like unevenness, the height of standard size is equal to center width of the unevenness and the width is 14.9mm (1.0° visual angle). Next, a standard size area is picked up at the location of the unevenness from the image drawn it on uniform density. That cut image is given 2D Fourier transform. The frequency band, which is attribute to the unevenness’s gradation distribution, is selected as  $\Delta f$ . Obtained power spectrum is nearly Gaussian distribution so that  $\Delta f$  means low frequency avoiding DC component. Finally, standard size area is picked up at the location of the unevenness from an input image without the unevenness. That is also given 2D Fourier transform. And obtained power spectrum is integrated in range  $\Delta f$ . In this study,  $\Delta f$  was the range from  $\lambda/3$  to the frequency at which the power decreased to 80%,  $\lambda$  is the center diameter or width of circle or belt-like unevenness areas, respectively.

The integrated power is defined “F-value”. F-value varies depending on the size of the unevenness because it determines the standard size. Fig. 4 shows the procedure of calculating F-value for the circle unevenness.

In case of the belt-like unevenness, an area which most subjects answered “visible particularly” is broken up into standard size pieces. F-values are calculated for each broken pieces once, and those averaged value is defined as F-value of the test image.

We confirmed between F-value and RT or the impression rank.

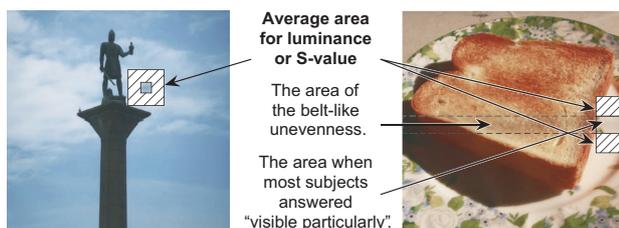


Fig. 3 Rough image of the average areas for luminance or S-value. The left is for circle, the right is for belt-like unevenness.

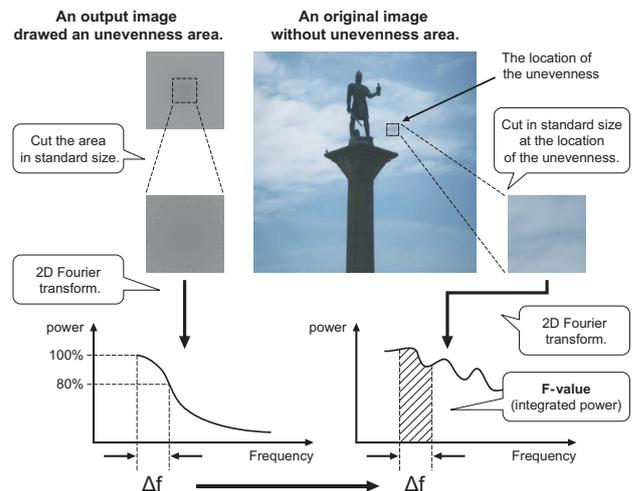


Fig. 4 The procedure to calculate F-value in case of test image for the circle unevenness. Results and Discussions.

### Results and Discussions

All results shown below are results averaged among all subjects on each test images. We confirmed that there are similar trends in results of individual subjects previously and considered about averaged results as overall trend.

#### 1. Correlation between RT and impression rank

Fig. 5 shows the correlation between RT and impression rank. The functions in the graphs are approximate functions. The correlation factors, between measured RT and RT calculated using the functions, were calculated. The absolute values of correlation factors were more than 0.96 and we found there were strong negative correlation. Therefore we thought that there was a correlation in a result shown in follows when the trends of each parameter versus RT and versus impression rank had opposite trends.

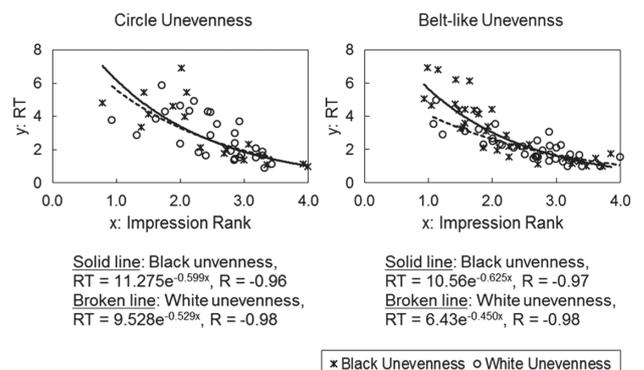


Fig. 5 Correlation between RT and impression rank.

#### 2. Influence of Luminance Ratio

The luminance ratio  $\Delta Y/Y$  of the unevenness distributed during 0.002 to 1.020. Fig. 6 shows Plots of RT or impression rank versus  $\Delta Y/Y$ , approximate

functions and correlation factors (R). R was calculated as correlation factor between measured RT or impression rank and that calculated from each approximate functions.  $\Delta Y/Y$  in above range correlated with RT very little and with impression rank weak. We considered the effect of  $\Delta Y/Y$  was vanishingly small because there were no obvious trends such as opposite or common behavior between RT and impression rank. Although luminance ratio of density unevenness affects visibility of it in uniform density images, we found that it appeared weak or no correlations when it was superimposed on general input image.

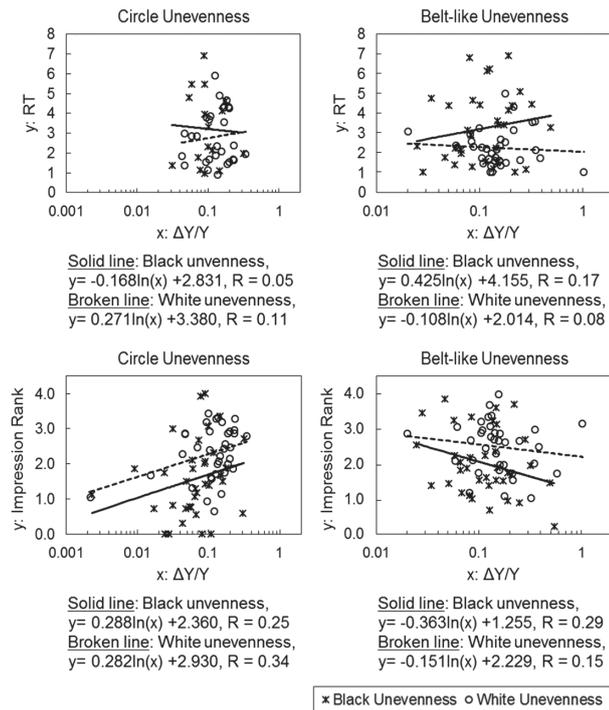


Fig. 6 The relation of RT or impression rank versus  $\Delta Y/Y$ .

### 3. Possibility of Saliency Affecting

Table 2 shows the results of correlation factors among S-value and RT or impression rank. We found that most statistic values of S-value did not correlate with RT but impression rank weakly. And those weak correlations had opposite trends between the white and black unevenness. Typical examples are shown in Fig. 7. The mechanism of this phenomenon was unclear. We expected that following 2 points would be keys to solve this problem. Human vision would be able to percept objects when there were black line on white background. And our test images could have been biased pictures which facilitate object perception by characteristics above. Finally, those statistic values of saliency suggested in this study were not proved as parameters affecting to visibility of density unevenness.

Table 2 Correlation factors (R) about S-value (S). The left: R between S and RT. The right: R between S and impression rank. Under lines mean that " $0.20 < R$ " and there is a correlation.

		S close to the unevenness	S of Summation	S of Average Deviation
Circle	Black	-0.05, -0.08	-0.04, <u>-0.42</u>	-0.09, <u>-0.45</u>
	White	-0.02, 0.04	<u>-0.23</u> , <u>0.31</u>	-0.37, <u>0.43</u>
Belt-like	Black	-0.04, -0.10	0.16, <u>-0.28</u>	0.14, -0.11
	White	<u>0.27</u> , <u>-0.24</u>	-0.09, <u>0.25</u>	-0.02, <u>0.32</u>

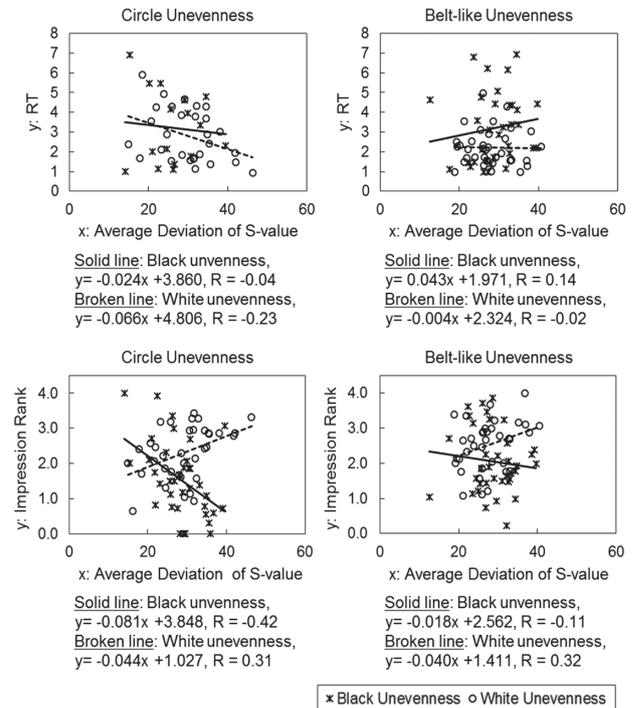


Fig. 7 The relations of RT or impression rank versus S-value.

### 4. Effect of F-value

Fig. 8 shows plots among F-value and RT or impression rank, correlation factors and approximately functions (R). The method of calculating R is same as that for  $\Delta Y/Y$ . We found that there were correlation between these parameters. The trend of RT was obviously opposite to that of impression rank. This results also support significance of the correlation. F-value is a component of spatial frequency of gradation distribution similar to that of the unevenness. It means that gradation distribution similar to that of the unevenness in an input images reduced visibility of the unevenness.

The correlations in case of belt-like unevenness were weaker than in case of circle. We expected that visibility of belt-like unevenness could be affected by its size (length) or continuity. All correlations shown in Fig. 8 were not strong. However, input images, which were background of each unevenness areas, included a lot kinds of noises. Therefore we recognized that an effect of F-value for visibility of the unevenness was practically strong.

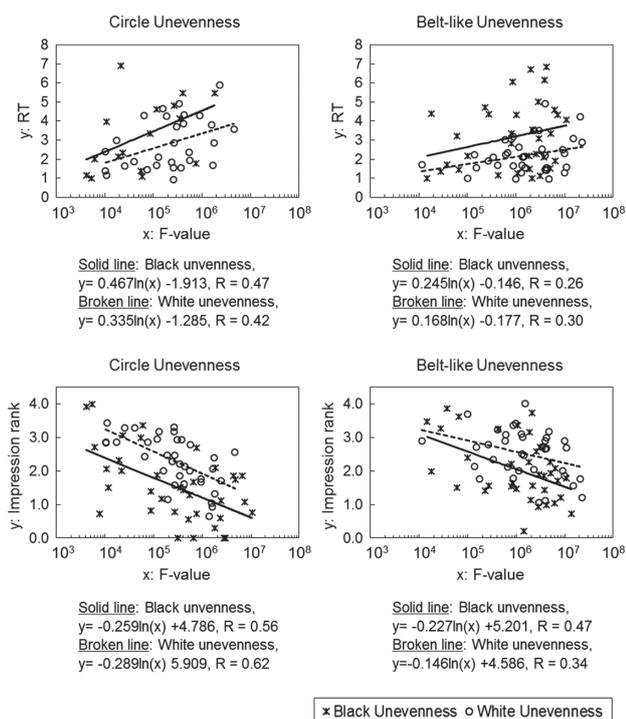


Fig. 8 The relations of RT or impression rank versus F-value. Data of which "8s < RT" is removed in upper 2 figures.

## Conclusions

Visibility of density unevenness caused by defects of a printer superimposed on a reproduction of an original input image was studied.

F-value, integration of spatial frequency of tone distribution in a range similar to that of a specific unevenness, has been verified with good correlation to results of visual psychophysical examinations for visibility of density unevenness. Visibility of density unevenness was weakened when the luminance distribution of the original input image at the location of the unevenness was similar to that of the unevenness.

Although luminance ratio of density unevenness affects visibility of it in uniform density images, it appeared weak or no correlations when it was superimposed on general input image.

Finally, we concluded F-value was considered to be a parameter for visibility of density unevenness.

Statistic values of saliency which we studied were not proved as parameters affecting visibility of the unevenness.

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## Author Biography

Natsuko Minegishi received her BS in physics from Ochanomizu University (2005) in Japan. In 2005, she joined R&D headquarters of Konica Minolta, Inc.. Her research has focused on designing developing sub-process on electrophotography for production printer. Concurrently she has been engaged in research for methodology of image quality evaluation using visual psychophysics.

Keiji Uchikawa, Ph. D, is a professor emeritus of Tokyo Institute of Technology, Japan. In 1980, he received Ph.D. in Department of Information Processing, Tokyo Institute of Technology. In 1980-1982, he worked as a post doctoral fellow in Psychology Department, York University, Toronto, Canada, in 1982-1986, an Assistant Professor in Tokyo Institute of Technology, in 1986-1987, a Visiting Researcher in Department of Psychology, UCSD, California, USA, in 1989-1984, an Associate Professor in Tokyo Institute of Technology, in 1994-2016, a Professor in Tokyo Institute of Technology, then retired in 2016. He is now working in Kanagawa University. He is interested in color vision, colorimetry, visual information processing, and psychophysics.

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