

# Separation of Granularity into Uniformity Deterioration Factors for Electrophotographic Images

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## Abstract

*It is important to not only evaluate granularity but also clarify the factors affecting it in order to improve the graininess of an image. A method for separating graininess into elements on the basis of the fluctuation of the background, lightness, and toner adherent area is proposed. By using this method following estimations will be enabled; 1. By obtaining the relation between the ordinary graininess and elements, the effect of each elements to the image quality can be estimated. This makes it possible to categorize printer. 2. Measuring by means of a polarizing plate, an effect of gloss ununiformity to the image quality can be detected. 3. By defining the standard contrast for a monochrome image, even though the dot density differs, the area fluctuation factor of graininess can be compared.*

## Introduction

Electrophotographic halftone images consist of a screen of 20 ~ 30 micron-sized dots made of toner. Therefore, the pattern shapes and image lightness of the screen may fluctuate even when there is a minimal amount of unevenness in toner adhesion, leading to a deterioration in granularity. Generally, the graininess in electrophotography imaging makes the images inferior to those of other imaging systems like offset and inkjet printing. Therefore, improving granularity is an important technological goal. To do so by optimizing the electrophotographic system, it is necessary to quantify graininess.

Dooley and Shaw of Xerox Corp. reported a method for measuring graininess on b/w images [1]. Imakawa et al. of Ricoh Co. Ltd. reported a method for color images based on the work by Dooley et al. [2]. The method uses frequency domain analysis for the fluctuations in colorimetric and lightness values, including corrections made by using the human visual transfer function (VTF) and the average lightness. The correlation between the subjective evaluated values and the estimated values shows good agreement at 0.95. This method enables us to evaluate graininess objectively.

Even though methods for evaluating graininess evaluation have been developed and made it possible to compare the image quality between print outputs quantitatively, graininess deterioration cause has not been specified yet.

The object of this study is to develop a method for revealing the cause of graininess deterioration in order to optimize the electrophotographic system.

## Methods

### Graininess equation

Graininess is expressed in the equation written below, where  $G_L(f)$  is a spatial frequency of lightness fluctuation and  $G_a(f)$ ,  $G_b(f)$  are the spatial frequency of hue fluctuation.  $VTF_L(f)$  is a

visual spatial frequency for the lightness, while  $VTF_a(f)$ ,  $VTF_b(f)$  are that for the hue.

$P(L_{ave})$  is a function having average lightness as a variable. The equation 4 is established even if average lightness differs, just like the correction equation by Dooley et al.

$$\text{Graininess} = P(L_{ave}) + \sum(G_L(f) \times VTF_L(f)) + \sum(G_a(f) \times VTF_a(f)) + \sum(G_b(f) \times VTF_b(f)) \quad (1)$$

### Graininess separation method

To describe the process in a simple manner, this report is based on monochrome graininess.

Graininess is defined in general as a two-dimensional frequency attribute of lightness fluctuation.

For an image made by area coverage modulation, lightness fluctuation can be divided into the following three elements.

1. Spatial frequency portion of toner adhesion area.
2. Spatial frequency portion of image lightness.
3. Spatial frequency portion of lightness fluctuation in background area due to toner scatter and dot gain.

The graininess equation is simplified by omitting  $a^*$ ,  $b^*$  related terms as

$$\text{Graininess} = P(L_{ave}) + \sum(G_L(f) \times VTF_L(f)) \quad (2)$$

$G_L(f)$  is obtained by a Fourier transform of spatial lightness distribution. Therefore, it can be expressed as

$$G_L(f) = F(g_L(x)) \quad (3)$$

, where  $F$  is a Fourier transform. The Fourier transform has the following property.

$$\begin{aligned} G_1(f) &= F[g_1(x)], G_2(f) = F[g_2(x)] \\ F[a_1g_1(x) + a_2g_2(x)] &= a_1F[g_1(x)] + a_2F[g_2(x)] \\ &= a_1G_1(f) + a_2G_2(f) \end{aligned} \quad (4)$$

Therefore, granulation is expressed like in equation 5 if the lightness is separated into two factors.

$$\begin{aligned} \text{Graininess} &= P(L_{ave}) \times \sum[(a_1G_1(f) + a_2G_2(f)) \times VTF(f)] \\ &= P(L_{ave}) \times \sum[a_1G_1(f) \times VTF(f)] + \\ &\quad P(L_{ave}) \times \sum[a_2G_2(f) \times VTF(f)] \end{aligned} \quad (5)$$

The contribution of every factor to the graininess is understood quantitatively by equation 5.

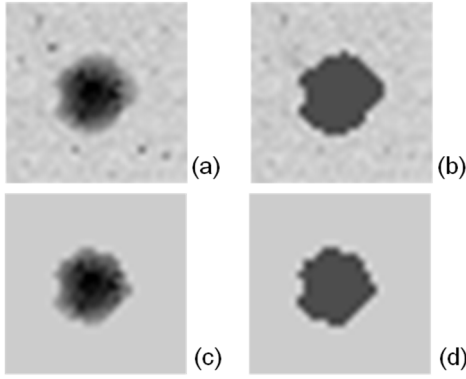


Figure 1. (a): An electrophotographic image. (b): An image replaced lightness of dot area with an average lightness. (c): An image replaced back ground area with an average lightness. (d): An image replaced the lightness of dot and background area with an average lightness each.

The dot image in Fig. 1(a) is separated into Figs. 1(b), (c), and (d). For an ordinary dot image (Fig. 1(a)), both the dot area and background area fluctuate. In contrast, in Fig. 1(b), the dot area lightness is replaced by the average value. In Fig. 1(c), the background area lightness is replaced by the average value. In Fig. 1(d), the dot area and background area lightness are both replaced by the average value.

$g_L(x)$  is broken down as follows.

$$g_L(x) = (g_b(x) - g_d(x)) + (g_c(x) - g_d(x)) + g_d(x) \quad (6)$$

$g_L(x)$ : lightness distribution of Fig. 1(a).  
 $g_b(x)$ : lightness distribution of Fig. 1(b).  
 $g_c(x)$ : lightness distribution of Fig. 1(c).  
 $g_d(x)$ : lightness distribution of Fig. 1(d).

$(g_b(x) - g_d(x))$  expresses the lightness fluctuation of the background area.  $(g_c(x) - g_d(x))$  expresses the lightness fluctuation of the dot area.  $(g_d(x))$  expresses the area fluctuation of the dots. Electrophotographic graininess was separated into factors deteriorating uniformity, as shown in equation 7..

$$\text{Graininess} = \text{Background Fluctuation Graininess} + \text{Lightness Fluctuation Graininess} + \text{Area Fluctuation Graininess} \quad (7)$$

The graininess of the image of Fig. 1 is expressed with the following relations.

$$\text{"Background Fluctuation Graininess"} = \{\text{Graininess}(\text{Fig. 1(b)}) - \text{Graininess}(\text{Fig. 1(d)})\} \quad (8)$$

$$\text{"Lightness Fluctuation Graininess"} = \{\text{Graininess}(\text{Fig. 1(c)}) - \text{Graininess}(\text{Fig. 1(d)})\} \quad (9)$$

If an image such as that in Figs. 1(b), (c), and (d) is made, and each graininess is estimated, the graininess is separated.

## Results and Discussion

### Example of graininess degradation

Graininess does not depend on the image area rate but rather differs depending on the printer's attributes. To estimate the graininess of an output device, the graininess must be measured on several image area rates, from highlight to solid. Figure 2 shows the results of graininess separation.

The background fluctuation graininess showed a large value in highlight area, where the image area was small, and the lightness fluctuation graininess became large in the dark area, where the image area was large. The graininess of area fluctuation was large in the mid-lightness area.

The ordinary graininess is plotted against the sum of the area fluctuation graininess, background area fluctuation graininess, and lightness fluctuation graininess, as shown in Fig. 3. From the graph and collinear approximation, they show a good match that proves equation 4.

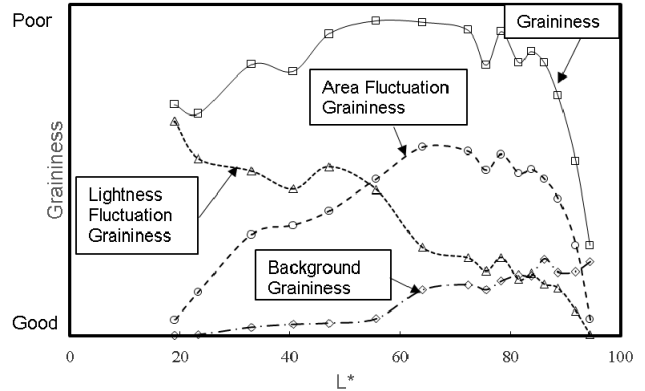


Figure 2. Results of graininess separation.

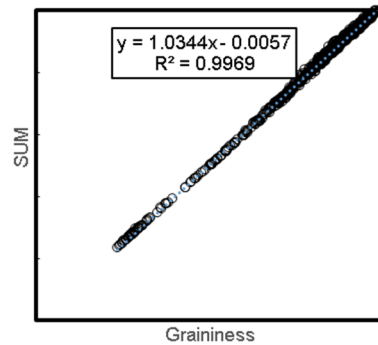


Figure 3. The ordinary graininess is plotted against the sum of the area fluctuation graininess, background area fluctuation graininess, and lightness fluctuation graininess.

### Comparison of average graininess between printers on the market

In Fig. 4, the ordinary graininess is plotted to lightness fluctuation graininess and area fluctuation graininess obtained from 37 pieces of data obtained from combined experimental

conditions including printers (n = 17), paper type, and output pattern.

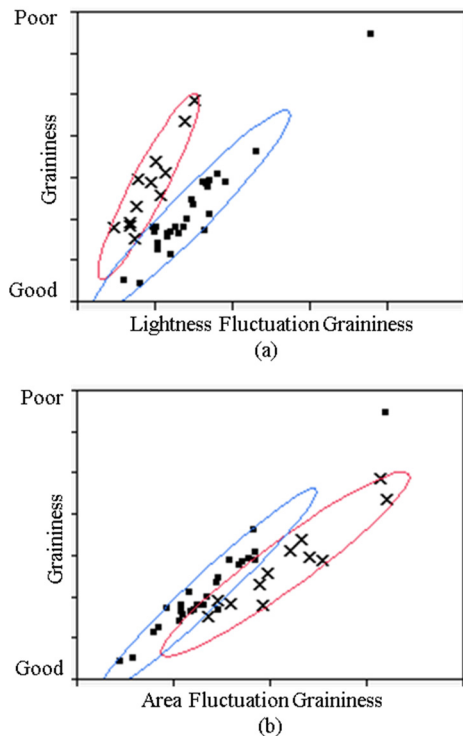


Figure 4. (a) Ordinary graininess to lightness fluctuation graininess. (b) Ordinary graininess to area fluctuation graininess.

A value is defined that shows the quality of a printer as average graininess. Said value is obtained by dividing the integral of graininess at every image rate by the lightness range. Each plot shows the average graininess. Even though the experimental conditions include both domestic and competitive printers and the measured pattern was also varied, the result showed the tendency of printers to be separated into two groups. As shown in Fig. 4, one is the dot plotted group and the other is the cross plotted group.

From a visual judgment, the cross-plotted group had a low dot lightness that scatters. In comparison, the dot-plotted group lightness was low, and the dot patterns were sharp. This indicates that printers on the market can be divided into the above dot and cross-plotted groups.

### Contribution of gloss element to the lightness fluctuation graininess

As the lightness of the toner adherent area includes surface gloss unevenness [3-5], it can be divided into the following.

1. Spatial frequency attribute of toner mass.
2. Spatial frequency attribute on gloss.

Removing the surface reflection by means of a polarizing plate gives the lightness fluctuation graininess without the effect of gloss unevenness.

For printer A, graininess was measured under the following conditions.

Tested environment = 3  
Sampling = 2 (start/end)  
Sampling amount = 3  
Printers = 3

Samples were obtained from the above experimental conditions.

The result is plotted on the top of Fig. 4 and is shown in Fig. 5 as circle plots. This shows that printer A's lightness fluctuation graininess was larger than that of common printers.

Estimating samples visually, the gloss unevenness was remarkable in the solid patch. It was considered that the enlargement of the lightness fluctuation graininess was due to gloss unevenness in the halftone as well. By removing the image gloss, lightness fluctuation graininess was lowered greatly (Fig. 6, triangle plots). In this way, an effect of gloss variation could be detected.

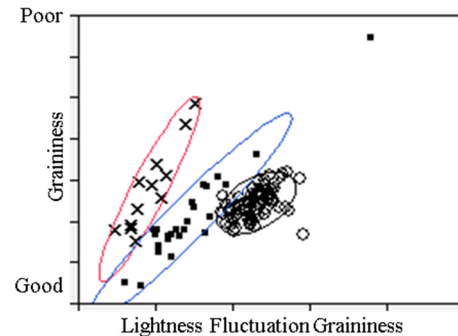


Figure 5. Lightness fluctuation graininess of Printer A plotted on top of figure 4(a).

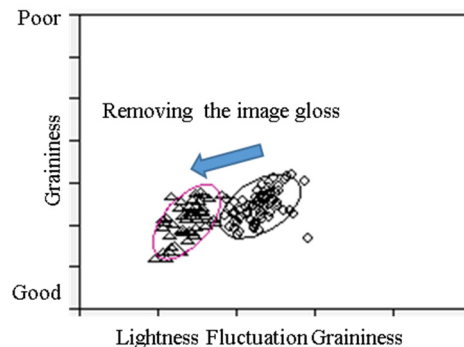


Figure 6. Graininess of removing the image gloss.

### Contribution of contrast to the area fluctuation graininess

Even though the distribution of the toner adherent area is exactly the same, if the contrast with the background area differs, the graininess will not be the same. The spatial frequency of the toner adhesion area depends on the average lightness of the image and background areas. Thus, the area fluctuation graininess contains the effect of deep contrast. Therefore, to omit the effect of contrast, the standard contrast value was defined and calculated the area fluctuation graininess under said contrast.

The standard contrast is defined for a monochrome image as follows. Figure 7 shows the relation between the area rate and its average lightness and that of the background lightness used in graininess separation and the lightness of the toner adherent area. The number of printers used in this test was 16, and including paper types, a total data was 23.

As is clear from Fig. 7, the average lightness does not take place right in the middle of the background and toner adherent area, but the area rate decides the relative relationship instead. Here, the subtraction of average lightness from background lightness is defined as  $L^+$  and that of the toner adherent area lightness from the average lightness as  $L^-$ .

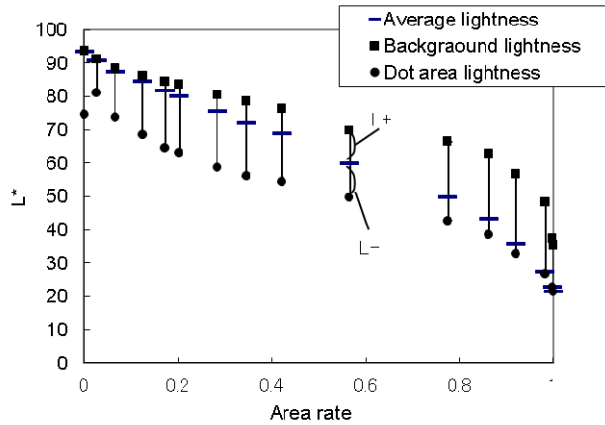


Figure 7. Relation between the area rate to its average lightness, and background lightness used in graininess separation to lightness of toner adherent area

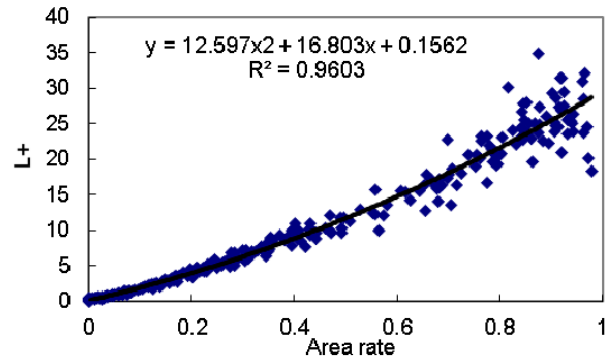
Figure 8 shows the distribution of  $L^+$  and  $L^-$  to the area rate. The distribution is approximated by using a polynomial expression of the area rate.  $L^+$  is a second degree polynomial, and  $L^-$  is a fourth degree polynomial, and both have an approximation ratio of over 0.9. The area rate is calculated from toner adherent area obtained by binarizing the image. Therefore, the average lightness of a measured sample and toner adherent area rate gives the standard toner adherent area lightness. The graininess obtained from said lightness is defined as the standard contrast area fluctuation graininess. When the area fluctuation graininess is larger than the standard contrast area fluctuation graininess, it means that the contrast of the measured sample is larger than that of the standard, and vice versa.

The subtraction the standard contrast area fluctuation graininess from the area fluctuation graininess is defined as the contrast graininess (CG). By defining CG, even though the contrast between paper and toner adherent area differs, the area fluctuation factor of graininess can be compared.

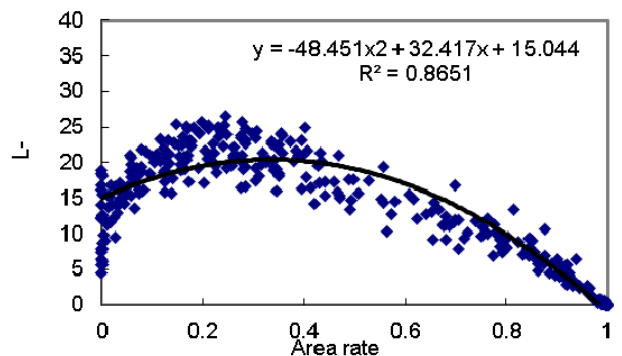
The spatial frequency of the toner adherent area rate depends on the average lightness and contrast. Now, by setting the contrast to the standard background, the spatial frequency attribute can be separated into two elements.

1. Spatial frequency element of toner adherent area under the contrast with the standard background contrast.
2. Spatial frequency element obtained from the difference with standard background contrast.

Shown in Fig. 9 is the area fluctuation graininess of an image printed on papers P1 and P2. The paper type was not similar. This shows that the image of paper P1 had a larger area fluctuation graininess. However, as shown in Fig. 10, you can see that CG was almost the same. The contrast of the image on paper P1 was larger than the image of paper P2. Therefore, the difference in area fluctuation graininess between these is due to each contrast.



(a)



(b)

Figure 8. (a) Distribution of  $L^+$  to area rate. (b) Distribution of  $L^-$  to area rate.

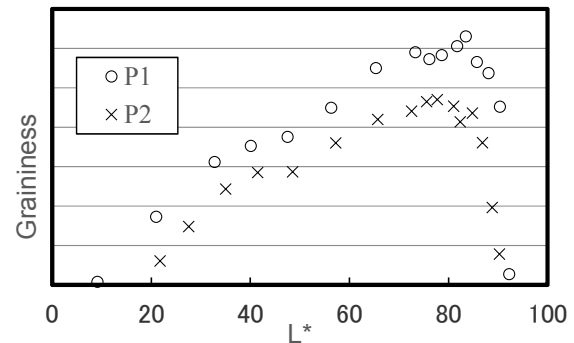


Figure 9. Area fluctuation graininess of the image printed on papers P1 and P2

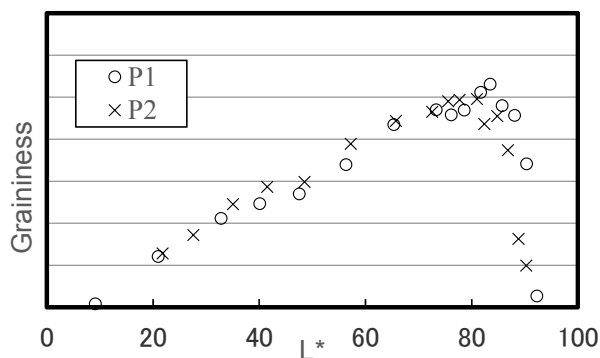


Figure 10. CG of the image printed on papers P1 and P2.

## Conclusion

A method for separating graininess into elements on the basis of the fluctuation of the background, lightness, and toner adherent area was proposed. As the sum of each element almost equaled the ordinary graininess, separation could be precisely.

Figure 11 shows a factor diagram along with each cause. By means of graininess separation, the cause of image deterioration was figured out in order to improve graininess.

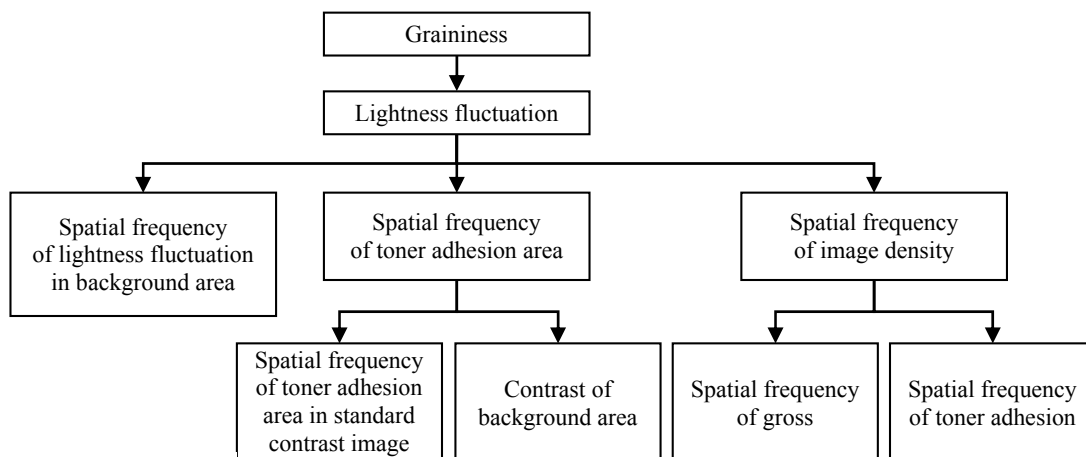


Figure 11. Factor diagram.

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## Author Biography

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