https://doi.org/10.2352/ISSN.2169-4451.2017.32.493

Development for Secondary Color Graininess Separation Method for the Electrophotographic Imaging

Yumiko Kishi, Kazuki Funahashi*, and Makoto Hino*; *Ricoh Company, LTD., 810, Shimoimaizumi, Ebina-shi, Kanagawa 243-0460, Japan*

Abstract

To improve the graininess of electrophotographic images, it is important to determine not only graininess values but also the root cause of graininess deterioration so as to provide feedback for use in electrophotographic image system development. In a previous report [1], a graininess separation method for clarifying the cause of graininess deterioration and its use to optimize an electrophotographic system was reported. It was clarified that using the method improved image processing, achieved better graininess, and made system development more effective. The method separates image graininess into 1) lightness fluctuation in background areas, 2) lightness fluctuation in dotted areas, and 3) dot size fluctuation. These factors are the root cause of image graininess deterioration. Therefore, being able to clarify the effect each factor has on graininess makes it possible to improve electrographic systems easily.. This report describes a graininess separation devised for secondary images and examines its validity. The method makes it possible to identify the cause of graininess degradation merely by taking a picture of an arbitrary secondary colour image. It also makes it possible to assume what colours need to be improved and what processing of the system need to be optimized. By using this method, electrophotpgrapic system can be optimized efficiently.

Introduction

In electrophotographic processing, halftone images of tens of micron-sized dots are generated with controlling toners that have micron-sized particle distribution. Therefore, a slight amount of unevenness in toner adhesion may change the halftone shape or lightness of the screen, which may cause deterioration of electrophotographic image graininess. In general, improving the graininess is one of the important technical issues in electrophotographic image processing since it is inferior to that obtained with other image processing methods like offset and inkjet printing. To optimize the electrophotographic process and improve image graininess, it is necessary to quantify the graininess.

Imakawa et al. of Ricoh Co., Ltd. [2] have reported a method for evaluating colour image graininess based on the work by Dooley et al. of Xerox Corp Reference [3]. Using this method made it possible to evaluate the graininess quantitatively.

Graininess reported Imakawa et al. 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.

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

The correlation between the subjective evaluated values and the estimated values shows good agreement at 0.95.

There are many other methods [4] [5] that quantify graininess, but to our knowledge few have been developed that use graininess values to improve image processing. In a previous report, a graininess separation method for clarifying the cause of graininess deterioration and its use to optimize an electrophotographic system was reported. Using it enabled us to clarify that it improved image processing through the better graininess it achieved and made system development more effective.

The method separated image graininess into three factors.

1) Lightness fluctuation in background areas: Lightness fluctuating in the background areas of images, it occurs as a result of optical dot gain or toner scattering.

2) Lightness fluctuation in dotted areas: Lightness fluctuating in the dotted areas of images, it occurs as a result of the amount of toner or unevenness in gloss.

3) Dot size fluctuation: Fluctuation in dotted areas, it occurs as a result of fluctuating dot size or shape.

These factors are the root cause of image graininess deterioration. Therefore, by clarifying the degree to which each affects graininess, electrophotpgrapic system can be optimized efficiently.

However, our previously reported graininess separation method is based on the premise of primary colour image separation and is not able to separate secondary colours. We therefore examined the correlation between primary and secondary colour image graininess, because we believed a method that could predict the latter from the former might be able to analyse the degradation factors for the former by separating the latter.

However, analysis results showed that the correlation differs from colour to colour. For example, the correlation between red (magenta-yellow overlaid colour) and magenta graininess is 0.71, while that between red and yellow graininess is about 0.1 (Fig.1). The correlation ratio between primary and secondary colour graininess is shown in Table 1. Since the ratio is less than 0.8, secondary colour graininess cannot be predicted accurately from a primary colour image's graininess.

In the secondary colour image example in Fig. 2, the secondary colour dotted area (blue) is formed where the primary colour dotted areas (magenta, cyan) overlap. It can be presumed that in a secondary colour image, the size of the mixed colour area, or colour fluctuation, affect the graininess.

Thus, in this report, we describe a secondary colour graininess separation method we propose that makes it possible to analyse the cause of graininess degradation for secondary colour images.

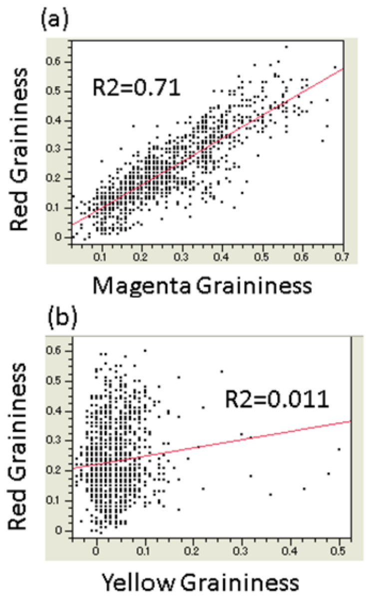

Figure 1. (a): Correlation between red (magenta-yellow overlaid colour) and magenta graininess. (b): Correlation between red and yellow graininess.

Table1: Correlation ratio between primary and secondary colour graininess for different colours.

	Red	Green	Blue
Cyan	-	0.53	0.45
Magenta	0.71	-	0.17
Yellow	0.011	0.06	-

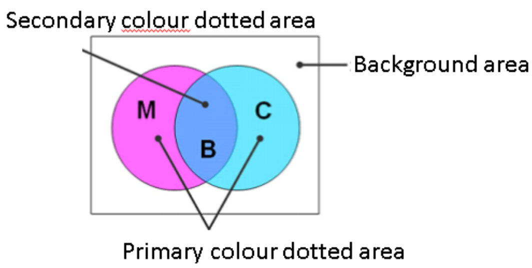

Figure 2. Separation of blue image.

Method

Logical decomposition of graininess

In our previously reported method, graininess is separated into the three factors. In the secondary colour example in Fig.2, there are non-overlapping primary colour dotted areas (cyan, magenta) and a secondary colour dotted area (blue) where the primary colour dotted areas overlap.

As shown in Fig. 3, the "Graininess of lightness fluctuation in dotted area" factor was broken down into:

1) "Graininess of primary colour lightness fluctuation", which indicates the effects of colour fluctuation in the primary colour dotted area, and 2) "Graininess of secondary colour fluctuation", which indicates the effects in the secondary colour dotted area.

1) Composition of specific area's flat colour image

To analyse an original image I0 (Fig. 4(a)), the four images listed below were composed. The methods used to distinguish dotted part areas from background part areas for each colour are separately described in "Image processing method for graininess separation".

I1 (Fig. 4(b)): Homogeneous colour image comprising primary and secondary colour dots, in which the primary colour dotted area and the secondary colour dotted area's L*a*b* values are each replaced with average values.

I2 (Fig. 4(c)): Homogeneous colour image comprising background and secondary colour dots, in which background area and secondary colour dotted area's L*a*b* values are each replaced with average values.

I3 (Fig. 4(d)): Homogeneous colour image comprising background and primary colour dots, in which background and primary colour dotted area's L*a*b* values are each replaced with average values.

I4 (Fig. 4(e)): Homogeneous colour image comprising background and primary/secondary colour dots, in which background area and primary/secondary colour dotted area's L*a*b* values are each replaced with average values.

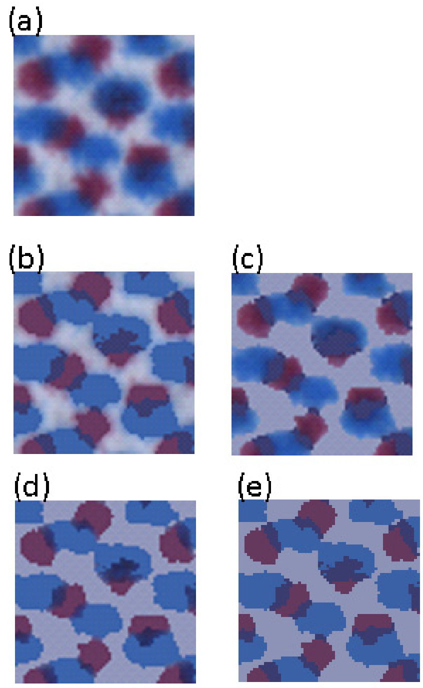

Figure 4. Composition of specific area's flat color image in secondary color image (blue). (a): Original Image (b): Primary and Secondary color dot's (c): Background and Secondary color dot's (d): Background and Primary color dot's (e): Background and Primary/Secondary color dot's homogeneous color image

2) Calculation of all images' graininess

The aforementioned Formula 1 was used to calculate the graininess values Gr(I0)、Gr(I1)、Gr(I2)、Gr(I3)、and Gr(I4) for the five images including the original image.

3) Calculation of the separated graininess

The following formulas were used to calculate the four graininess values Gr1(I0)、Gr2(I0)、Gr2'(I0)、and Gr3(I0).

$$Gr_1(I_0) = Gr(I_1) - Gr(I_4) \quad (2)$$

$$Gr_2(I_0) = Gr(I_2) - Gr(I_4) \quad (3)$$

$$Gr_{2'}(I_0) = Gr(I_3) - Gr(I_4) \quad (4)$$

$$Gr_1(I_0) = Gr(I_4) \quad (5)$$

These values mean:
Gr1(I0) is the difference between an image in which the background colour fluctuates and one in which it does not. Thus, it is the graininess caused by the background fluctuation (hereafter, “Background colour fluctuation graininess”).
Gr2(I0) is the difference between an image in which the primary colour dotted part fluctuates and one in which it does not. Thus, it is the graininess caused by the primary colour dots’ colour fluctuation (hereafter, “Primary dot colour fluctuation graininess”).
Gr2'(I0) is the difference between an image in which the secondary colour dot part fluctuates and one in which it does not. Thus, it is the graininess caused by the secondary colour dots’ colour fluctuation (hereafter, “Secondary dot colour fluctuation graininess”).
Gr3(I), which is the image (I4) graininess calculated when the entire background part, as well as the primary and secondary colour dots’ colour fluctuation, was eliminated. Thus, it is thought to be the graininess caused by the dotted area square measure fluctuation (hereafter, “Dot size fluctuation graininess”).

Thus, for secondary colour images, graininess can be analysed by decomposing the original image's graininess into “Background colour fluctuation graininess”, “Primary dot colour fluctuation graininess”, “Secondary dot colour fluctuation graininess”, and “Dot size fluctuation graininess”.

Image Processing method for graininess separation

The processing flow for graininess separation is briefly described below.
1) Determination of colour for the target image for analysis.
2) Calculation of the image area ratio for each colour toner.
3) Distinction of the toner colour for each pixel.
4) Calculation of the separated graininess
The following describes these steps in more detail.

1) Determination of colour for the target image for analysis

Determine the colour of the target image for the analysis. Colour is determined by the location of the average L*a*b* colour value of the image in the CIELAB space.
1)-1: Print the gradation chart of solid to background for CMYRGB, then measure the L*a*b* value for each target toner and paper in advance.
1)-2: Determine the colour from CMYRGB's solid L*a*b* in the gradation chart, then the position of the target image's average L*a*b* value in the *a*b flat surface. (Fig. 5)

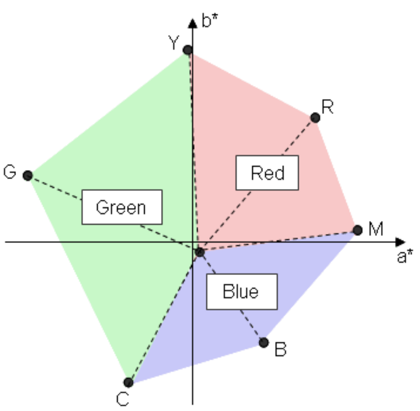

Figure 5. Determination of color for the target image for analysis.

2) Calculation of image area ratio for each colour toner

Using the nature of the average L*a*b* value of the target image, i.e., that it is relocated for each colour toner (CMY)'s image area ratio in the CIELAB space, enables the image area ratio to be calculated simply. We examined the relationship between the primary colour's gradation chart of the colour degree and the real area ratio. It was found that the area ratio for an arbitrary primary image can be calculated by using a formula that calculates the relative colour difference (ΔE) between colour of a paper, a solid image, and a target image. The area ratio of duplicated parts is expressed by multiplying the area of each primary colour image. The difference between a single colour's image area ratio and a duplicated part's area ratio becomes the primary colour part's area ratio.

By using 1), 2), the toner colour for each pixel is judged and the separated graininess is calculated.

Results

An example of graininess separation

Figure 6 shows the results obtained in applying the graininess separation method to a blue halftone image. The unseparated original graininess is shown as “Original graininess". The figure shows that the following tendencies were observed for the graininess factors.
1) Background colour fluctuation graininess:
Higher when the halftone dotted area ratio is smaller.
2) Primary dot colour fluctuation graininess:
Maximum when close to 50% of the halftone area ratio, and lower when the image consists of a solid colour or the background area ratio is large.
3) Secondary dot colour fluctuation graininess:
Higher when the halftone dot area ratio is larger, that is, close to that of a solid image.
4) Dot size fluctuation graininess:
Maximum when close to 50% of the halftone area ratio, and lower when the image consists of a solid colour or the background area ratio is large.

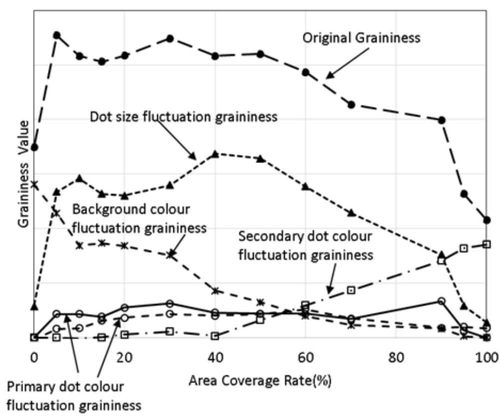

Figure 6. Separation results for secondary colour graininess: (1). Background colour fluctuation graininess: Higher when halftone dot area ratio is smaller. (2). Primary dot colour fluctuation graininess: Maximum when close to 50% of the halftone area ratio, lower when the image consists of a solid colour or the background area ratio is large. (3). Secondary dot colour fluctuation graininess: Higher when the halftone

dotted area ratio is larger, that is, close to that of a solid image. (4). Dot size fluctuation graininess: Maximum when close to 50% of the halftone area ratio, lower when the image consists of a solid colour or the background area ratio is large.

Except for the graininess of dot size fluctuation, we took all these tendencies into account because of the high correlation between separated graininess and fluctuated area's ratio. For instance, for a solid part with a halftone area ratio of 100% the only fluctuation was in the secondary colour dotted area. This shows that as the area ratio becomes larger, the "Secondary dot colour fluctuation graininess" also becomes larger.

The sum of the separated graininess factors for which these tendencies were observed was calculated for validation. Figure 7 shows a graph for which the vertical axis is this sum and the horizontal axis is the original graininess. Since the approximate slope in the graph is almost 1 and the contribution is good, the original graininess can be explained properly by using the four graininess factors. It can be considered that the margin of error between the original graininess and the sum of the separated graininess factors is due to the fact that the graininess calculated without high frequency spectrum in order to reduce the calculation amount.

In summary, we were able to explain the original graininess properly by using the "Background colour fluctuation graininess", "Primary dot colour fluctuation graininess", "Secondary dot colour fluctuation graininess", and "Dot size fluctuation graininess" factors.

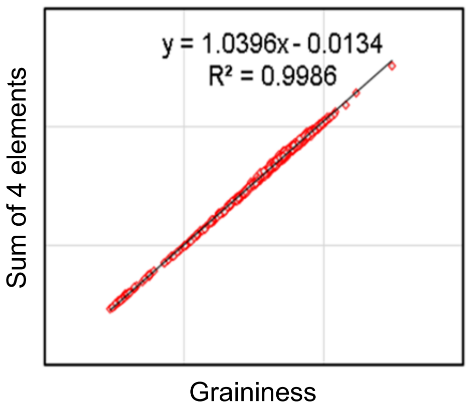

Figure 7. Graininess is plotted against the sum of the 4 elements.

An example of analysis using the graininess separation method

Comparing the graininess of images obtained with Printer A and Printer B, which use the same toner, we found that the graininess was worse for the Printer B images (Fig. 9). We used our method to examine the reason for this. As the figure shows, the graininess gap was higher when the halftone area ratio was about 20-40%. The graininess separation was measured for an image with a halftone area ratio of 20%. The contribution of each of the separated graininess factors to the overall graininess for both printers is shown in Fig. 10. It was found that the contribution of the primary colour (magenta) lightness fluctuation in the dotted area was higher for Printer B than for Printer A. Comparing the image structure, the area ratio of magenta was 27% higher for Printer B than for Printer A. It may be considered that the development or transfer processing of magenta may not have been optimized. Therefore, it may be possible to improve the graininess in various ways, such as by optimizing the magenta development and transfer processes or changing the amount of magenta toner.

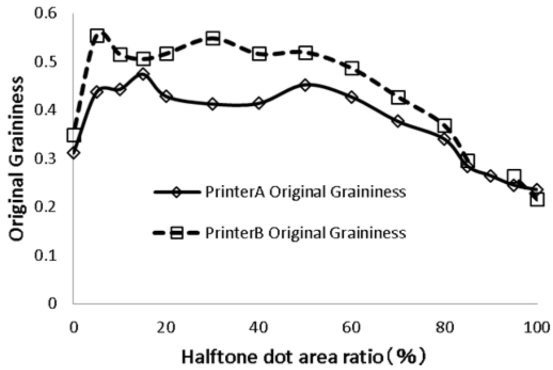

Figure 8. Comparison of original graininess of Printer A and B images.

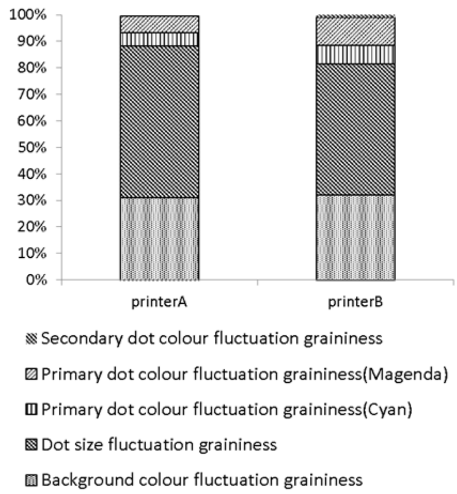

Figure 9. Contribution of each separated graininess factor.

Conclusion

The graininess separation method for secondary colour images have devised and examined its validity. The method enables the cause of graininess deterioration to be identified merely by taking a picture of an arbitrary secondary image. It also makes it possible to assume what colours need to be improved. By using this method, electrophotpgrapic system can be optimized efficiently.

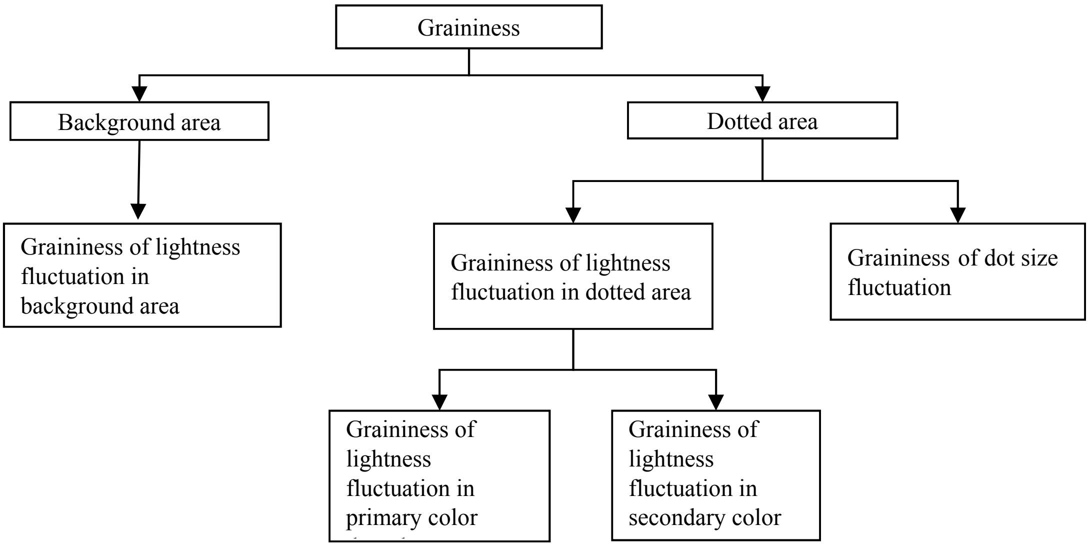

Figure 3. Graininess separation

References

[1] Y. Kishi et al., “Separation of Granularity into Uniformity Deterioration Factors for Electrophotographic Images”, NIP31 International Conference on Digital Printing Technologies, 2015. pp. 246-250

[2] S. Imakawa et al., “Noise Evaluation Method for Halftone Color Image”, Ricoh Technical Report, 1997, No. 23, SEPTEMBER, pp. 53-59.

[3] R.P.Dooley, R.Shaw: “Noise Perception in Electrophotography”, J. Appl. Photogr. Eng., 1979, Vol. 5, No. 4, pp. 190-196.

[4] Peter G. Engeldrum, "Absolute graininess thresholds and linear probability models," Proceedings of the IS&T's 1998 PICS Conference, 1998, 231-236.

[5] K. Miyata, Y. Miyake, “Evaluation of sharpness and graininess in digital imaging system and its application to improve total image quality”, Proc. SPIE 4300, Color Imaging: Device-Independent Color, Color Hardcopy, and Graphic Arts VI, 290 (December 21, 2000)

Author Biography

Yumiko Kishi received her master's degree in Chemistry from Ochanomizu University in 1994. Since 1994, she has worked at Ricoh Company, Ltd. Her work has been focused on the image evaluation of hard copies and the numerical simulation of electrophotographic systems. She is a member of the Imaging Society of Japan.