Effect of Dot Percentage and Phase on Perceptive Recognition of Rosette Pattern

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Keywords : Dot array, Halftone, Moire, Rosette, Screening

Abstract : In screening process, rosette pattern is seen on the print formed by halftone dot array. It is inevitable to appear the rosette pattern on the image using the half toning process.

In this report. the effect of dot coverage ratio and phase of dot array on visibility of rosette pattern is analyzed by numerical method such as FFT. The result is compared with perceptive recognition experiment about rosette pattern in the image.

It is shown from this study that the rosette pattern is recognized most clearly by the observers when the halftone dot coverage ratio is around 30%. The perceptive recognition intensity of rosette pattern, however, vary with the phase of dot array.

1. Introduction

Color reproduction by the halftone dot area modulation method has been traditionally used in press printing before applying it to new color imaging technology such as a printer and copying machine. A volume of ink is controlled by changing the dot coverage ratio, so the tone of image is changed along with it. A various colors are made by overlaying the halftone dots with different dot coverage ratio of four colors on white paper.

However, the halftone dot area modulation follows the moire pattern, because the four colors halftone dot array regularly with close dot interval for

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each color are overlaid on the paper. In other words, a pattern with lower frequency component than that of the original halftone dot image is newly formed on the image. The moire pattern that occurs on printing image is generally called rosette since this pattern like a petal of the rose.

In this report, the effect of the dot coverage ratio and phase of dot array on visibility of rosette pattern is studied numerically in spatial frequency domain. The result is compared with perceptive recognition experiment about rosette pattern in the image. Four items shown below are discussed in following section.

1. Generation mechanism of rosette pattern.
2. Relation between the dot coverage ratio and the perceptive recognition of rosette pattern.
3. Relation between the phase shift of halftone dot array and the perceptive recognition of rosette pattern.
4. Relation between the phase shift of halftone dot array and the color reproduction.

2. Generation mechanism of rosette pattern.

When the image is formed by using the halftone dot area modulation, the screen angle of C, M and K is set 15, 45 and 75 degrees, to minimize the influence by moire. In other words, the moire pattern has the most distant spectrum mutually in a spatial frequency domain. The absorption coefficient functions of two different coloed dot images that incline 30 degree mutually are represented by f and g, then the absorption coefficient function r of the overlaid dot image can be shown with **equation 1**.

$$r(x,y) = f(x,y) \cdot g(x,y) \qquad \text{[equation 1]}$$

F, ***G*** and ***R*** are spatial Fourier transforms of each function f, g and r respectively.

$$F(\omega_x, \omega_y) = \iint f(x,y) \cdot e^{-i(\omega_x x - \omega_y y)} dxdy \qquad \text{[equation 2]}$$

Then we get the relation.

$$R(\omega_x, \omega_y) = F(\omega_x, \omega_y) * G(\omega_x, \omega_y) \qquad \text{[equation 3]}$$

Equation 3 is driven from **equation 1** by using convolution theorem of Fourier transforms, where * represents convolution integral.

The halftone dot images of screen angle 15 and 45 degrees are shown in **Figure 1a** and **1b**. Overlaid image of **Figure 1a** and **1b** is shown in **Figure 1c**.

Fig.1a Dot image
(15deg. . 30%)

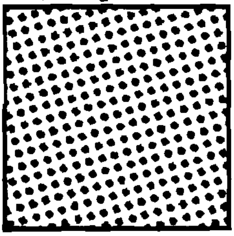


Fig.1b Dot image
(45deg. . 30%)

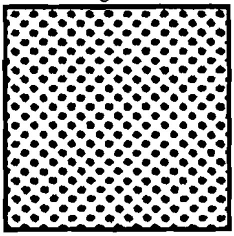


Fig.1c Overlaid dot image
(15 and 45deg. . 30%)

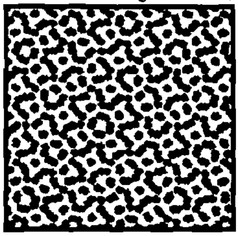


Fig.1d Power spectrum
of **Fig.1a**

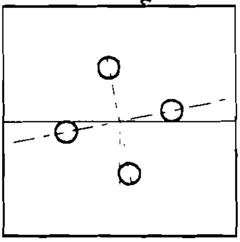


Fig.1e Power spectrum
of **Fig.1b**

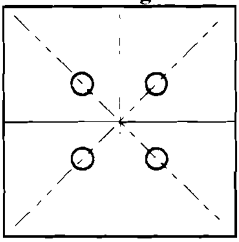


Fig.1f Power spectrum
of **Fig.1c**

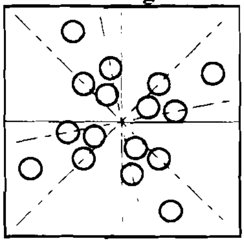


Fig.1g Overlaid image
Fig.1d and Fig.1e

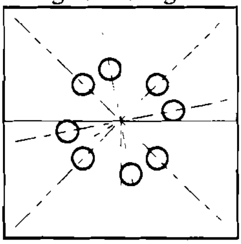


Fig.1h Sum spectrum
(15 and 45 deg.)

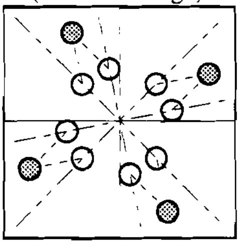


Fig.1i Different spectrum
(15 and 45 deg.)

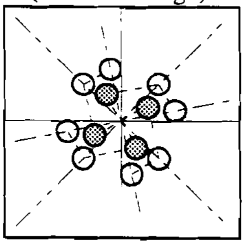


Fig.2 Sum spectrum
(15, 45 and 75 deg.)

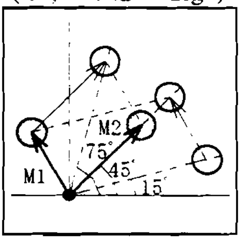


Fig.3 Overlaid dot image
(15.45 and 75deg.. 30%)

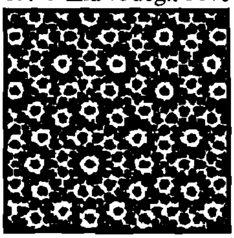
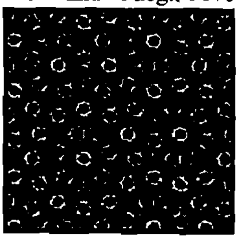


Fig.4 Overlaid dot image
(15.45 and 75deg.. 50%)



A power spectrum of the image from **Figure 1a** to **Figure 1c** are shown in **Figure 1d** to **Figure 1f**. Overlaid image of **Figure 1d** and **1e** is also shown in **Figure 1g**. The sum and difference spectrums are appearing in **Figure 1f** other than the original spectrum in **Figure 1g**. A lower frequency component spectrum makes larger pattern structure than **Figure 1a** and **1b.**

Since a difference of the screen angle of two halftone dot array are 30 degrees, the frequency difference M_1 between **Figure 1a** and **1b** is given by **equation 4**.

$$M_1 = 2 \cdot \sin\frac{30^\circ}{2} \cong 0.518 \qquad \textbf{[equation 4]}$$

Therefore, the moire pattern that has $1/M_1$ (1.932) times interval of halftone dot and deviated 15 degrees from axis of original pattern is formed on the halftone dot image.

Furthermore, the newly spectrum is formed on the halftone dot image (see **Figure 2**) by 3rd overlaid dot image when three kinds of dot array are overlaid. In this case, the frequency difference M_2 is given by **equation 5**.

$$M_2 = \sqrt{M_1^2 + 1^2 - 2 \cdot M_1 \cdot \cos(45^\circ)} \cong 0.732 \qquad \textbf{[equation 5]}$$

The moire pattern that has $1/M_2$ (1.366) times interval of halftone dot and deviated 45 degrees from axis of original pattern is formed on the halftone dot image. In other words, rosette pattern is formed with the combination of 1.932 and 1.366 times interval of original halftone dot.

3. Relation between the dot coverage ratio and the perceptive recognition of rosette pattern.

3.1. Perceptive recognition experiment about rosette pattern in the image.

Perceptive recognition experiment is carried out on a preparing sample image. The screen angle of four colors of C, M, K and Y are set up 15, 45, 75 and 0 degrees. Nine kinds of overlaid halftone dot images that have dot coverage ratio from 10% to 90% in 10% intervals are prepared (shown in **Figure 3** and **4**). Because emphasis is put on a shape analysis of the moire pattern, low resolution dot image having 4 line/cm are prepared.

By using nine kinds of overlaid halftone dot image, four items stated below is examined.

1. The perceptual detectability of moire pattern.
2. The shape of moire pattern.
3. The recognition point of moire pattern.
4. The recognition strength of moire pattern.

Result of perceptive recognition experiment is shown in **Table 1**.

Many observers are recognized rosette pattern as circle. Rosette pattern is recognized mainly by the shape without a color. And it is recognized strongly in a comparatively low dot coverage ratio.

Table.1 Result of perspective recognition experiment

1	Recognition : 94%, No recognition : 6%
2	Circle : 58%, Doughnut : 12%, Double circle : 12%, Hexagon : 6%, Pentagon : 6%, Square : 6%
3	Shape : 94%, Colored pattern : 6%
4	10% : 96p, 20% : 124p, 30% : 131p, 40% : 148p, 50% : 103p 60% : 71p, 70% : 41p, 80% : 24p, 90% : 0p

3.2. Analysis of rosette pattern by two dimensional FFT.

The structure of moire is studied for two color overlaid halftone dot image by numerical analysis.

Twenty kinds of halftone images having coverage ratio from 5% to 95% in 5% intervals are generated as the bit map images in digital memory. The shape of halftone dot is square. The similar halftone images of screen angle 45 degrees are also prepared. Overlaying combination of two images having different angle with different coverage ratio creates four hundreds kinds of halftone dot images. The overlaid images are monochrome (a halftone dot part is numeric "0" and a background part is "255" irradiance), because rosette pattern is recognized only by the shape even in colored dot as shown previous section.

Fig.5 Overlaid dot image
(15 and 45deg. , 30%)

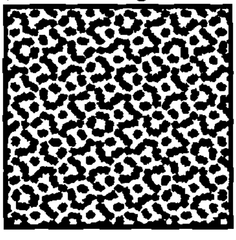
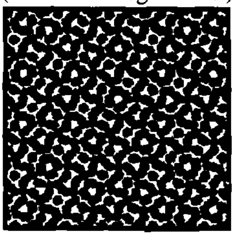


Fig.6 Overlaid dot image
(15 and 45deg. , 50%)



A spectrum of created 400 images are calculated by using two dimensional FFT. A ratio C of the spectrum value of the moire to average value over image (zero frequency) is driven from the spectrum. Examples of several halftone images are shown in **Figure 5** and **6**. The result is shown in **Figure 7**. The magnitude of C is proportional to the size of a circle in those figures. The ratio C has the biggest value around 30% dot coverage ratio.

A ratio C corresponds to the recognition strength of rosette pattern, because the experiment about perceptive recognition gives same result. (**Table.1** (4))

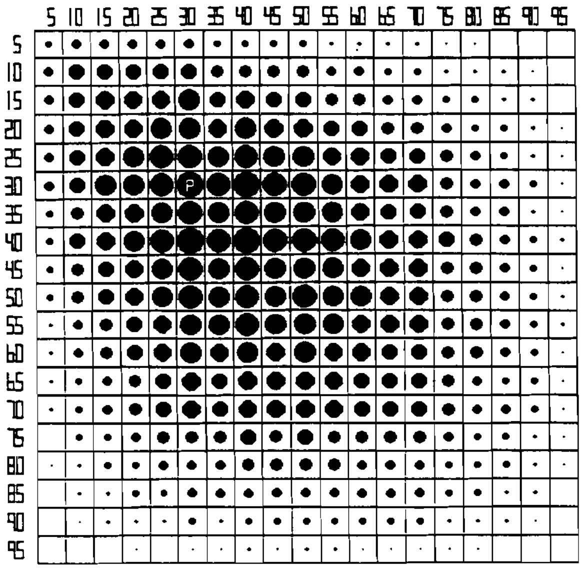


Fig.7 Relation between the dot coverage and the ratio C

4. Relation between the phase shift of halftone dot array and the perceptive recognition of rosette pattern.

Appearance of rosette pattern would be clear when each dot array is overlaid in a proper condition. The pattern may change in shape with the different mutual position (phase) of dot array.

This suggest that it may be able to reduce recognition strength of rosette, by changing a mutual phase of dot array.

4.1. The case of two images overlaid.

Moire pattern of two overlaid images having different phase is analyzed. The screen angle of halftone dot image of yellow is generally put with the angle of 0 or 90 degrees. There are three combination which are 15 and 45 degrees, 45 and 75 degrees, and 75 and 15 degrees (**Figure 8**). Three combined images having different angle makes the same type of moire.

Fig.8a Overlaid dot image (15 and 45deg. . 30%)

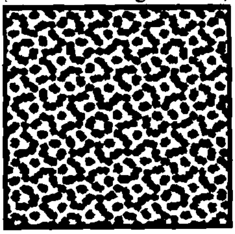


Fig.8b Overlaid dot image (45 and 75deg. . 30%)

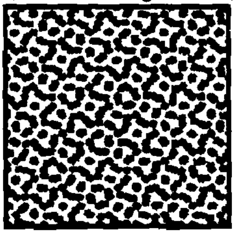
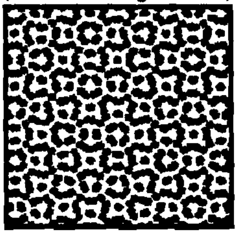


Fig.8c Overlaid dot image (75 and 15deg. . 30%)



Therefore, screen angle 15 and 45 degrees is used for study on phase effect.

The halftone images used in this research are as follows.

- 30% dot area coverage.
- 10 pixel dot interval.
- 512*512 pixel in size of image.
- A digital image and printed image.

Since the main interest is in the point of moire pattern, all halftone dots are set up to monochrome. 30% dot coverage is used for this study because recognition strength is highest at this ratio as shown in previous section. A center of gravity position of one dot is put just over the dot of 2nd image. The axis of screen for base image is called u-axis, and other vertical axis to u is v-axis. The one-tenth of dot interval is used a unit length "d" for phase shift. Phase shift is chosen in sixteen combination of several direction and length. The examples of combined image are shown in **Figure 9**.

The total coverage ratio of overlaid halftone dot images are calculated. The result is shown in **Table 2**. The difference between maximum and minimum total coverage ratio is 0.2 %.

The perceptive recognition experiment is carried out on sixteen kinds of monochrome output images from a video printer. The sixteen images are presented to observer for perceptual comparison. The observer gives points of rank according to recognition strength of rosette pattern in each image. In the case of giving equal recognition strength, the same point is counted. The result is shown in **Table 3**. The resolution of the output image by using video printer is 14 lpi. There is not a significant difference of perceptive recognition between each images in the evaluation result. This means that the rosette pattern on sixteen kinds of images have the same recognition strength. From the aforementioned analytical result, the moire pattern formed by two kinds of dot array regard as the same pattern even in different phase deviation.

Fig.9a Overlaid dot image
15 and 45deg., 30%
(u = 0, v = 0)

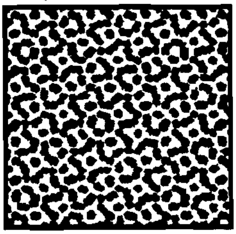


Fig.9b Overlaid dot image
15 and 45deg., 30%
(u = 5d, v = 0)

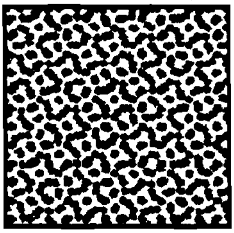


Fig.9c Overlaid dot image
15 and 45deg., 30%
(u = 5d, v = 5d)

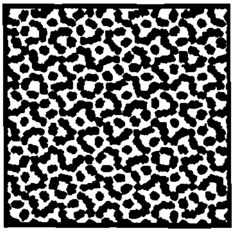


Table.2 Relation between phase shift and dot coverage ratio [%]

	u= 0	u=3d	u=5d	u=8d
v= 0	51.2	51.2	51.3	51.3
v=3d	51.2	51.4	51.4	51.2
v=5d	51.3	51.3	51.3	51.3
v=8d	51.3	51.2	51.2	51.4

Table.3 Result of perceptive recognition experiment [point]

	u= 0	u=3d	u=5d	u=8d
v= 0	229	215	220	226
v=3d	209	199	208	222
v=5d	192	209	215	203
v=8d	198	200	219	181

4.2 The case of three images overlaid.

The three overlaid images are also treated.

Figure 10 shows the overlaid dot images of screen angle 75 degrees which are put on the images overlaid screen angle 15 and 45 degrees with four different phases. Dot size and phase shift is the same as two images overlaid case. The origin of overlay coordinate is selected so that both dots in an image of screen angle 15 and 45 degrees overlap just in a center of gravity.

The monochrome and colored dot images are analyzed. The colored dot image having the screen angles of the 15, 45, 75 and 0 degrees for K, M, C and Y are used for a comparison with monochrome.

A shape of the moire pattern is classified. The relation between the magnitude of phase shift and the shape of the moire pattern is shown in **Figure 11**. The moire patterns are able to be classified into four category shown below.

No.1 The circular pattern with a black (white) point. (**Figure 10a**).
No.2 The usual rosette pattern (**Figure 10b**).
No.3 The crystal pattern like snow (**Figure 10c**).
No.4 The intermediate pattern of No.1 and No.2 (**Figure 10d**).

Fig.10a Overlaid dot image
(u = 0, v = 0)

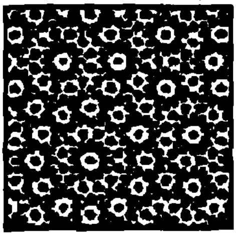


Fig.10b Overlaid dot image
(u = 5d, v = 5d)

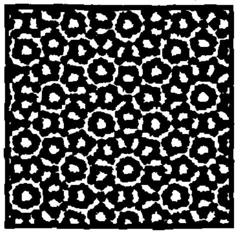


Fig.10c Overlaid dot image
(u = 5d, v = 0)

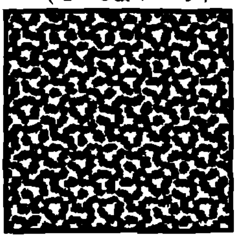
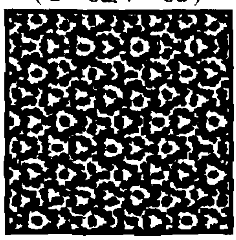


Fig.10d Overlaid dot image
(u = 8d, v = 8d)



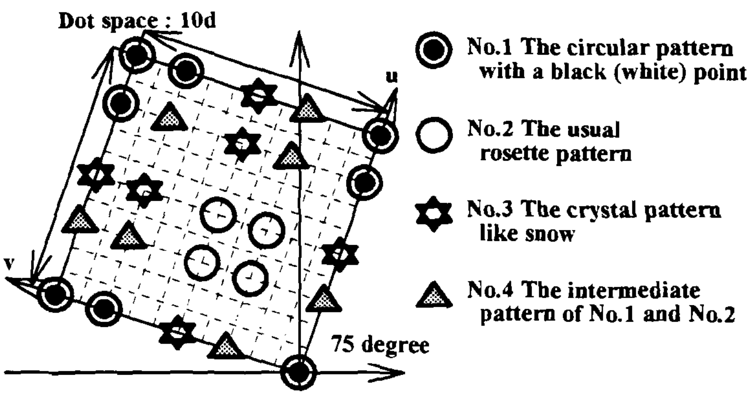


Fig.11 Relation between the phase shift and the shape of moire pattern

A power spectrum of a rosette component is also analyzed and the result is shown in **Table 4** and 5.

In this case, the dot array of screen angle 75 degree is overlaid to the images 15 and 45 degrees, so a power spectrum of a rosette component is equal to the mean value of each spectrum components.

Finally, a perceptive recognition experiment is carried out on the monochrome and coloed dot output image from a video printer. In perceptive recognition experiment method, the ranks of recognition strength are given by observer, like the process as shown previously. The result of points obtained from ranking of perceptive recognition strength of each moire is given in **Table 6** and 7. The same tendency is obtained for both of the monochrome and coloed image.

The moire pattern is strongly recognized at u=5d, v=5d, and u=0, v=0. In other words, the moire pattern of No.1 and No.2 in above category is recognized strongly.

From this result, it is conceivable that the recognition strength of the rosette pattern can be reduced by shifting the phase of dot array. These perceptive recognition results also correspond to the numerical analysis shown above.

Table.4 A ratio C value
(the case of monochrome image)

	u= 0	u=3d	u=5d	u=8d
v= 0	0.67	0.22	0.56	0.22
v=3d	1.78	1.44	1.33	1.44
v=5d	1.78	1.67	1.33	1.89
v=8d	0.89	0.56	0.67	0.89

Table.5 A ratio C value
(the case of colored image)

	u= 0	u=3d	u=5d	u=8d
v= 0	0.44	0.33	0.67	0.44
v=3d	0.78	0.78	0.78	0.89
v=5d	1.00	0.78	0.89	0.89
v=8d	0.67	0.33	0.67	0.56

Table.6 Result of perceptive recognition experiment [point]
(the case of monochrome image)

	u= 0	u=3d	u=5d	u=8d
v= 0	225	96	102	131
v=3d	88	200	224	135
v=5d	112	236	240	127
v=8d	186	101	108	112

Table.7 Result of perceptive recognition experiment [point]
(the case of colored image)

	u= 0	u=3d	u=5d	u=8d
v= 0	162	122	168	117
v=3d	126	225	229	132
v=5d	119	242	233	149
v=8d	135	115	160	112

5. Relation between the phase shift of halftone dot array and the color reproduction.

5.1 The case of two color overlaid.

A digital dot image used here for an analysis has characteristics as shown below.

- The dot size is 10*10 pixel, and dot shape is square.
- Each dot array of C, M have screen angle 15 and 45 degrees.
- An image size is 500*500 pixel.

In the case of 80 pixel/mm resolution, one side of image become to about 6 mm. Phase shift distance is defined in same manner as previous section. The sixteen kinds of dot images changed along 45 degrees axis against screen angle are prepared.

The coverage ratio of each coloed dot in 500*500 pixel are counted to reduce the tristimulus values and L*a*b* value. The sixteen divided area consisting of 4*4 parts from 500*500 pixels are analyzed separately.

In this research, a color chart of SCID image sample prepared by Japanese standard organization is used to calculate the tristimulus values of phase shifted images. The density of 100% colored and paper part on the color chart are measured by using the colorimeter CR-241 produced by Minolta. A density value is transformed to tristimulus values by using the **equation** 6. A D65 light source, 2 degrees viewing condition, and 1.8mm detecting aperture is used for measurement.

$$D_x = -\log_{10}(\frac{X}{X_0}) \qquad \textbf{[equation 6]}$$

$$X = a_w X_w + a_c X_c + a_m X_m + a_y X_y + a_k X_k + a_r X_r + a_g X_g + a_b X_b \qquad \textbf{[equation 7]}$$

where D_X is the measured density, X is the tristimulus value of the objects, X_0 is tristimulus value for D65 light source. It is similar to Y and Z.

The tristimulus values of a dot image are calculated by using the equation of Neugebauer (**equation 7**) from the dot coverage ratio and the tristimulus values of each 100% coverage colored part.

In the case of 30% dot coverage ratio, the relation between the phase shift and the color difference is shown in **Table 8**. The relation between the dot coverage and the color difference is shown in **Table** 9. Maximum value of color difference in 4*4 parts is 0.553, and a color difference of maximum and minimum value is 0.23 (**Table 8**). Almost of same color reproduction is obtained in the most part on the image. In other words, in the case of two color overlaid, phase shift cause no color change.

In the case of halftone dot coverage ratio from 5% to 95%, L*a*b* values of each phase shift images are shown in **Figure 12**. The L*a*b* values are almost equal to each phase shift images.

Table.8 The peak of color difference in 4*4 parts
(The case of two color overlaid)
coverage 30%

	u= 0	u=3d	u=5d	u=8d
v= 0	0.471	0.369	0.424	0.359
v=3d	0.434	0.403	0.500	0.323
v=5d	0.494	0.493	0.553	0.419
v=8d	0.537	0.328	0.468	0.479

Table.10 The peak of color difference in 4*4 parts
(The case of four color overlaid)
coverage 30%

	u= 0	u=3d	u=5d	u=8d
v= 0	1.496	1.328	1.394	1.566
v=3d	1.043	1.025	1.236	1.266
v=5d	0.990	1.124	1.151	1.025
v=8d	1.375	1.439	1.200	1.233

Table.9 Relation between the coverage ratio and the color difference
(The case of two color overlaid)

coverage [%]	dE* (Max)	ex. 1 (u, v)		ex. 2 (u, v)		dE* (Min)	ex. 1 (u, v)		ex. 2 (u, v)	
5	0.043	0	0	0	5d	0.000	5d	0	5d	3d
10	0.070	0	5d	3d	5d	0.000	8d	0	0	3d
15	0.093	0	0	8d	5d	0.000	3d	0	0	5d
20	0.101	8d	3d	8d	5d	.0.000	0	0	5d	5d
25	0.114	0	0	8d	5d	0.000	8d	0	5d	5d
30	0.119	3d	5d	8d	5d	0.000	3d	0	0	5d
35	0.159	3d	5d	8d	5d	0.000	0	0	5d	5d
40	0.111	0	0	8d	5d	0.000	0	3d	5d	5d
45	0.076	0	0	8d	5d	0.000	3d	0	5d	0
50	0.069	8d	5d	0	8d	0.000	0	0	8d	0
55	0.123	0	0	5d	3d	0.000	3d	0	5d	0
60	0.065	3d	0	3d	5d	0.000	0	0	5d	8d
65	0.173	3d	5d	8d	8d	0.000	0	0	0	3d
70	0.195	0	0	8d	5d	0.000	0	0	8d	3d
75	0.166	5d	3d	8d	3d	0.000	5d	0	5d	8d
80	0.195	3d	5d	8d	5d	0.000	0	0	8d	3d
85	0.230	0	0	8d	5d	0.000	0	0	3d	8d
90	0.182	0	0	8d	5d	0.000	0	0	8d	0
95	0.043	0	0	3d	0	0.000	0	0	0	3d

Table.11 Relation between the coverage ratio and the color difference
(The case of three color overlaid)

coverage [%]	dE* (Max)	ex. 1 (u, v)		ex. 2 (u, v)		dE* (Min)	ex. 1 (u, v)		ex. 2 (u, v)	
5	0.050	0	5d	0	5d	0.000	8d	0	8d	3d
10	0.219	0	3d	5d	3d	0.002	5d	0	5d	3d
15	0.626	0	5d	5d	5d	0.008	3d	5d	5d	5d
20	1.135	0	5d	5d	5d	0.012	5d	0	5d	8d
25	1.928	0	5d	5d	5d	0.014	5d	3d	5d	5d
30	2.800	0	5d	5d	5d	0.021	5d	0	5d	8d
35	3.558	0	5d	5d	5d	0.019	5d	3d	3d	5d
40	4.371	0	5d	5d	5d	0.029	5d	0	5d	8d
45	5.581	0	5d	5d	5d	0.052	5d	0	5d	8d
50	6.398	0	5d	5d	5d	0.055	3d	8d	8d	8d
55	7.427	0	5d	5d	5d	0.014	3d	8d	8d	8d
60	8.666	0	5d	5d	5d	0.031	3d	8d	8d	8d
65	8.753	0	5d	5d	5d	0.021	3d	8d	8d	8d
70	8.570	0	5d	5d	5d	0.108	5d	0	8d	5d
75	7.451	0	5d	5d	5d	0.041	5d	0	5d	8d
80	5.598	0	5d	5d	5d	0.044	0	3d	8d	8d
85	3.458	0	5d	5d	5d	0.021	5d	0	8d	5d
90	1.506	3d	5d	5d	5d	0.000	0	0	0	8d
95	0.346	5d	8d	5d	8d	0.000	3d	0	0	3d

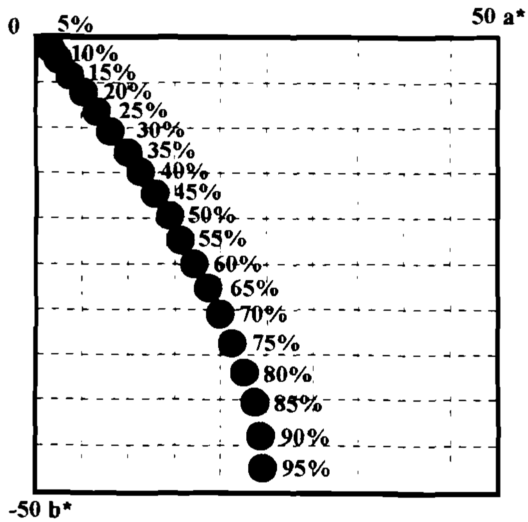


Fig.12 Relation between the phase shift and L*a*b* value
(Dot coverage from 5% to 95%, two color overlaid)

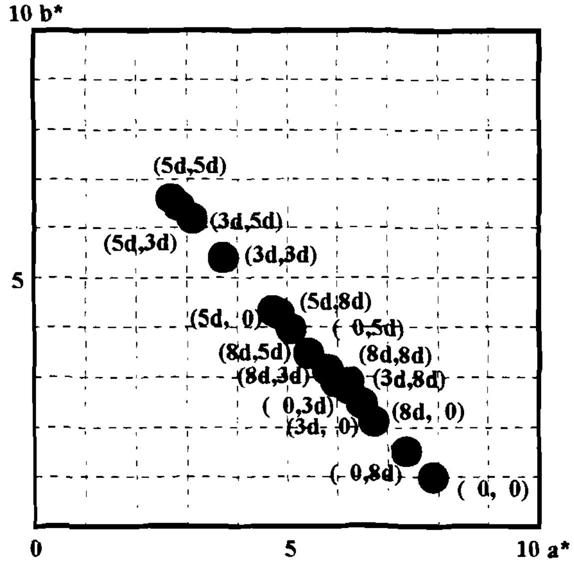


Fig.13 Relation between the phase shift and L*a*b* value
(Dot coverage 65%, four color overlaid)

5.2 The case of four color overlaid.

The four color overlaid images are also analyzed. The screen angle of Y, M, C and K are 0, 15, 45 and 75 degrees, respectively. The items analyzed here is similar to two overlaid case.

In the case of 30% dot coverage ratio, the relation between the phase shift and the color difference is shown in **Table 10.** The relation between the coverage ratio and the color difference is shown in **Table 11**. Maximum value of color difference in 4*4 parts is 1.566, and a color difference of maximum and minimum is 0.576 (**Table 10**).

The color difference become 8.753 in the case of 65% dot coverage ratio (**Table 11**). This difference of two colors is recognized obviously. Furthermore, a color difference become the biggest in most halftone dot coverage ratio, when a phase shift is u=0, v=0 and u=5d, v=5d. L*a*b* values of each phase shift images are shown in **Figure 13**. L*a*b* values of each images are distributed on a straight line of yellow and red. From these results, in the case of four color overlaid, phase shift cause the color change.

6. Conclusion.

From this study, the following became obvious.

Moire pattern having a cycle of 1.932 times and 1.366 times of original halftone dot is appeared on printing image. Rosette pattern is formed by the combination of these pattern.

Recognition strength of moire pattern has peak value when a halftone dot coverage ratio is 30%. This result corresponds with the analytical result that is lead from two dimensional Fourier transform. The usefulness of an analytical method that used two dimensional Fourier transform is confirmed.

The shape of moire pattern is changed with a phase shift of dot array. In the case of two color overlaid, the shape of moire pattern is not changed. However, a shape of moire pattern generated by overlaying three images is changed with a phase shift of dot array. On the other hand, the recognition strength of the moire pattern is weakened by the phase shift. From the analytical result of reproduced color, a phase shift causes a color change.

Finally, the halftone dot area modulation certainly follows the moire pattern, but the recognition strength of the moire pattern can be weakened by controlling a phase of four overlaid images.