A Study of Harmonics Screen for Four Color Reproduction

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Abstract

In conventional halftone screen technology, orthogonal screens are widely used. The screen angles for three colors of cyan (C), black (K) and magenta (M) are 15°, 45° and 75°. Another one yellow (Y) is 0° or 30°. Since Y crosses to M (C) with the shallow angle difference of 15° when Y is 0°, a low frequency moiré occurs in red (green), and it becomes an image defect. In the xerography process that uses the multiplex transfer of color toners, more remarkable moiré especially occurs as compared with offset printing. In order to reduce this moiré, "four-color harmonics screen" which sets spatial frequency components in four colors as a harmonics relation, has been developed. This is achieved by sharing a part of spatial frequency between two colors using a nonorthogonal screen. There are two kinds of combination of four colors that have such a relation. One is a ring coupling that shares one spatial frequency component between two colors respectively, and combines four colors to the shape of a ring. Another is a star coupling. In this case, three colors share three spatial frequency components of remainder one color respectively. In this paper, two screen-sets are introduced as each example of screen designing. In conventional halftoning, a color moire could not sufficiently be prevented, if a high-frequency screen like 300 lpi was not used. However, a color moiré can be prevented by "four-color harmonics screen" even if the screen-frequency is 150 to 200 lpi.

Introduction

In an orthogonal screen, screen angles of C, K, and M are 15°, 45°, and 75° in many cases. This screen-set has "three-color Harmonics relation" which can control especially an unnecessary color moiré in three colors.

This is explained as follows. The relation between the basis vector defined from the address on the real space plane and the spatial frequency vector on the spatial frequency plane is shown in Fig. 1.[1] Here, the spatial frequency vector $\boldsymbol{w}_1$ and the basis vector $\boldsymbol{r}_1$ are orthogonal; $\boldsymbol{w}_2$ and $\boldsymbol{r}_2$ are orthogonal too. The magnitude values are calculated by the following equations.

$$|\boldsymbol{w}_1| = 1 / (|\boldsymbol{r}_2| \sin\theta) \quad (1a)$$

$$|\boldsymbol{w}_2| = 1 / (|\boldsymbol{r}_1| \sin\theta) \quad (1b)$$

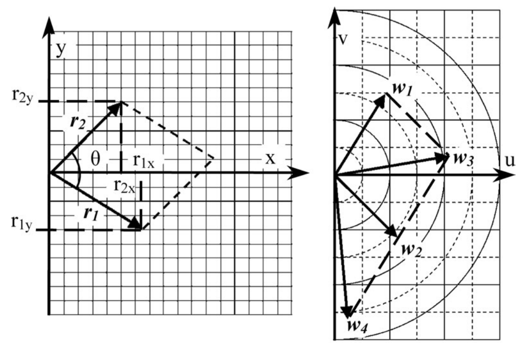


Figure 1. Conversion of the basis vector in the real space plane (left) to the spatial-frequency plane (right)

The spatial frequency vector $\boldsymbol{w}_3$ is the vector sum of $\boldsymbol{w}_1$ and $\boldsymbol{w}_2$, and the spatial frequency vector $\boldsymbol{w}_4$ is the vector difference. The vector $\boldsymbol{w}_3$ and one diagonal line of the parallelogram made by the basis vectors are orthogonal. The vector $\boldsymbol{w}_4$ and another diagonal line are orthogonal too. θ is the angle between $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$, given by the following equation.

$$\theta = \tan^{-1}(r_{2y} / r_{2x}) - \tan^{-1}(r_{1y} / r_{1x}) \quad (2)$$

In the screen-set of 175 lpi (lines per inch), the relation between basis vectors and spatial frequency vectors is shown in Fig. 2. In this paper, a spatial frequency vector is rewritten as a screen vector of which the unit is lpi.

When three colors are separated by 30° with the same screen-frequency, the screen vectors make an equilateral triangle, like M2, C2 and K1 shown in Fig. 2. This means "three-color harmonics relation". Figure 3 (a) shows a typical rosette pattern of "three-color harmonics relation". Fig. 3 (b) is a moiré pattern of Y and M when Y is placed at 0°. This red moiré is a vector difference of Y_1 (Y_2) and M_2 (M_1) shown in Fig. 2, and becomes 46 lpi. Furthermore, a green moiré between Y and C is generated conversely, and much lower frequency component occurs in gray of three colors.

On the other hand, since coordinates of dots are quantized in digital halftoning, it is difficult to make an exact harmonics relation. When an irrational tangent screen is used, the relation of three colors can be made as a good accuracy.[2] Or even if three screen vectors do not form an equilateral triangle, a low frequency moire is prevented when three screen vectors are closed relation.[3,4]

In any case, there is a problem of placement of fourth color remaining.

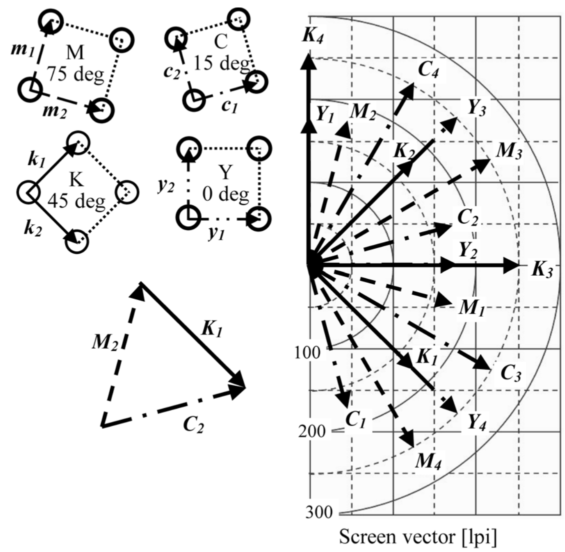
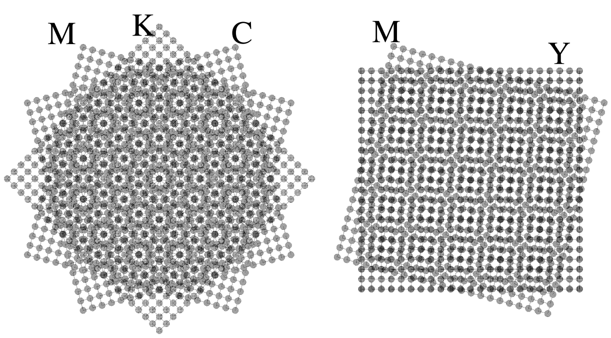


Figure 2. Relation between basis vectors and screen vectors of orthogonal screen-set



(a) M, C and K 30° shifted

(b) M and Y 15° shifted

Figure 3. Moiré patterns of a conventional orthogonal screen-set

Theory and Designing

Sharing of a Screen Vector

In order to make a harmonics relation of four colors, one screen vector is shared between two colors. An example of dot placement is shown in Fig. 4. Each basis vector is written by the relative coordinate of a digital grid, as follows.

$\boldsymbol{c_1}$: (4, 12), $\boldsymbol{c_2}$: (12, -4)
$\boldsymbol{k_1}$: (10, 10), $\boldsymbol{k_2}$: (15, -5)

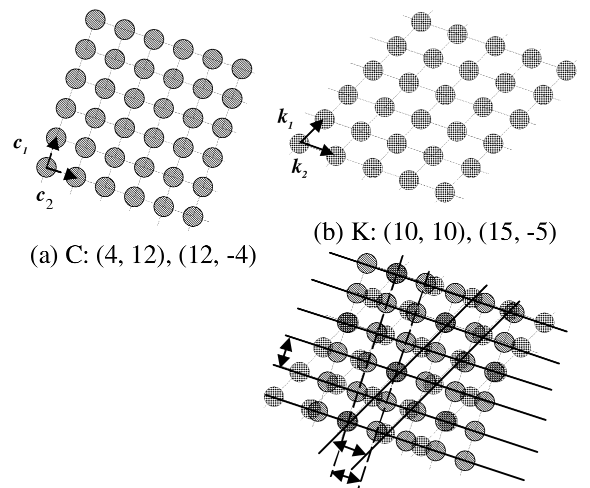
There are following features in this dot placement.

- In basis vectors $\boldsymbol{c_2}$ and $\boldsymbol{k_2}$, both angles are equal, but those magnitudes differ.
- Although the angles of basis vectors $\boldsymbol{c_1}$ and $\boldsymbol{k_1}$ differ, the perpendicular component of $\boldsymbol{c_1}$ to $\boldsymbol{c_2}$ and the perpendicular component of $\boldsymbol{k_1}$ to $\boldsymbol{k_2}$ are equal.

According to this condition, the dots of two colors overlap changing a phase on each line. Therefore, the two colors share the screen vector that crosses these lines right-angled. On the other hand, since the angles of basis vectors $\boldsymbol{c_1}$ and $\boldsymbol{k_1}$ differ, other screen vectors differ.

Ring Coupling

If M and Y are placed on the reverse point of C and K shown in Fig. 4, one screen vector will be shared between M and Y also. Furthermore, a screen vector is shared also between M and K and between C and Y. Figure 5 (a) shows a ring shape in which four colors are combined, where one screen vector between two colors is shared. Figure 5 (b) shows a rosette pattern in which these four colors are stacked. Therefore, even if it is the 4th composite color, a low frequency moiré does not generated. The basis vectors and screen vectors of these four colors are shown in Fig. 5 (c) and Fig. 5 (d).



(a) C: (4, 12), (12, -4)

(b) K: (10, 10), (15, -5)

(c) Superposition of 2 colors

Figure 4. Sharing the screen vector between two colors

The screen vector of each color is calculated as shown in Table 1, when the resolution of basis vector is 2,400 dpi. M and C are 190 lpi orthogonal; Y and K are nonorthogonal having 170 to 190 lpi as a principal component. The average screen-frequency is 183 lpi. This screen-set is called 180-type.

Threshold processing of this screen-set is realized by Holladay's algorithm.[5] For example, Holladay's Tile of K is 40 x 5 cells with 25 shifts.

Star Coupling

If two basis vectors approach an equilateral triangle, the size of the third screen vector becomes same grade as the first and the second. Star coupling can be created when each screen vector of one color is shared by other three colors. Figure 6 (a) shows a model of star coupling when K is centered. An example of basis vectors and screen vectors are shown in Fig. 6 (c) and (d). Figure 6 (b) shows a rosette pattern in which these four colors are stacked.

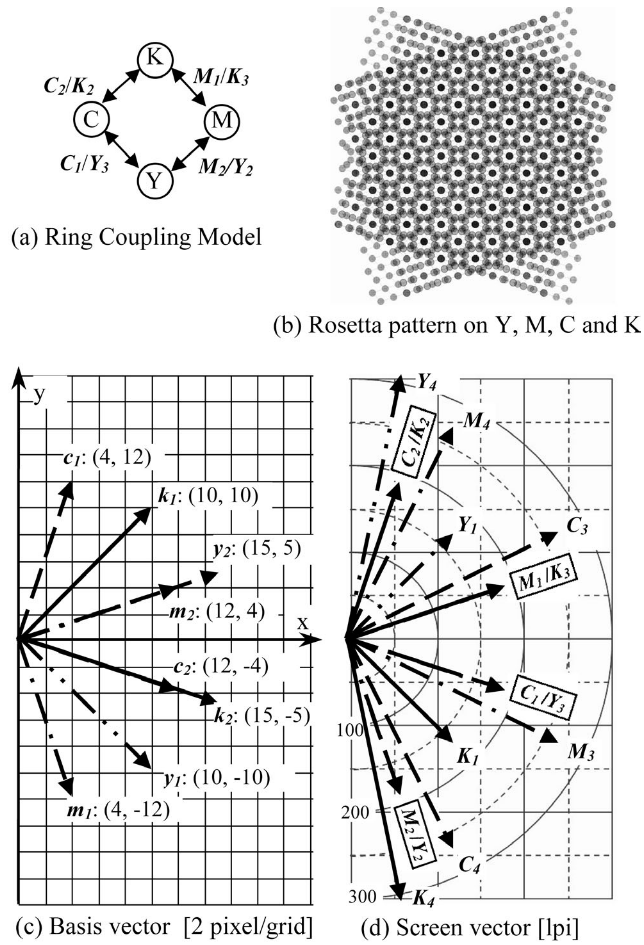


Figure 5. Features of 180-type harmonics screen

Table 1. Screen vectors of 180-type [lpi/deg.]

	K	C	M	Y
1st	169.7/-45	189.7/-18.4	189.7/18.4	169.7/45
2nd	189.7/71.6	189.7/71.6	189.7/-71.6	189.7/-71.6
3rd	189.7/18.4	268.3/26.6	268.3/-26.6	189.7/-18.4
4th	305.9/-78.7	268.3/-63.4	268.3/63.4	305.9/78.7

As well as a previous example, when the resolution is 2,400dpi, the screen vector of each color is calculated as shown in Table 2. The average screen-frequency is 156 lpi. Therefore, this screen-set is called 150-type.

Experiment

Printing Result

In order to print a binary image of 2400 dpi using a xerographic printer, a laser scanner of a digital color-copying machine (Fuji Xerox DCC500) was modified into 2,400 dpi. The spot size of this laser scanner is about 50 microns. This machine can directly output an image data processed by a computer before to the laser drive circuit.

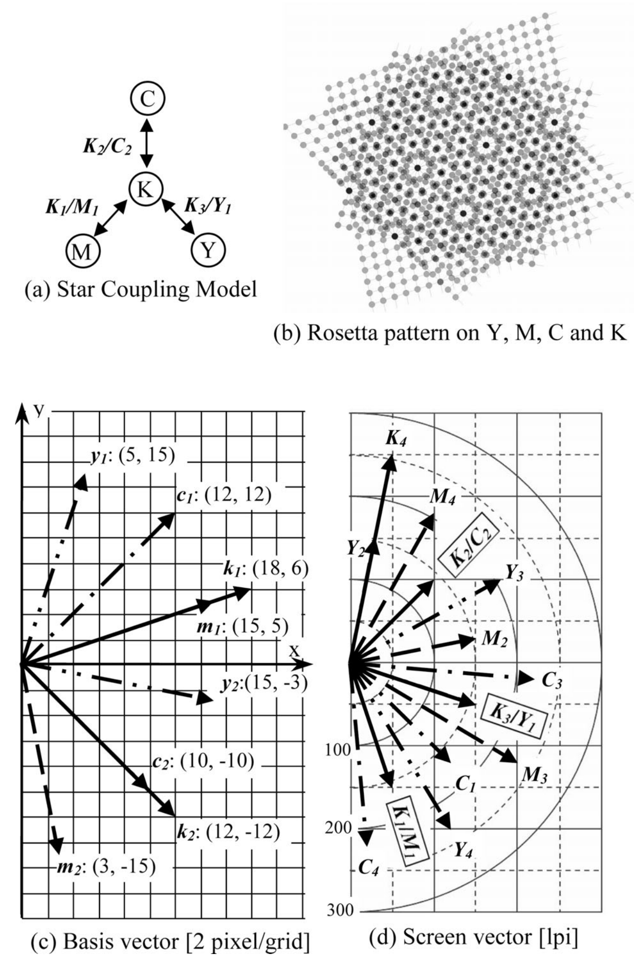


Figure 6. Features of 150-type star coupling harmonics screen

Table 2. Screen vectors of150-type [lpi/deg.]

	K	M	C	Y
1st	158.1/-71.6	158.1/-71.6	169.7/-45.0	158.1/-18.4
2nd	141.4/45.0	153.0/11.3	141.4/45.0	153.0/78.7
3rd	158.1/-18.4	233.2/-31.0	220.9/-5.2	205.9/29.1
4th	255.0/78.7	205.9/60.9	220.9/-84.8	233.2/-59.0

Figure 7 shows dot pattern of 180-type. Each input density is 20%. For each photograph, tone and contrast are adjusted so that it can be recognized in black and white. Figure 7 (e) shows a moiré pattern of C and M. Figure 7 (f) shows a moiré pattern of Y, M, and C. The squares applied on all photographs are the basic cell of 85 lpi/45°. All of four colors have it in common. Therefore, even if Y overlaps onto Blue to make gray, the moire pattern is still the basic pattern. It is the same even if K overlaps further. For this reason, unnecessary low frequency moiré is not generated in the combination of any colors.

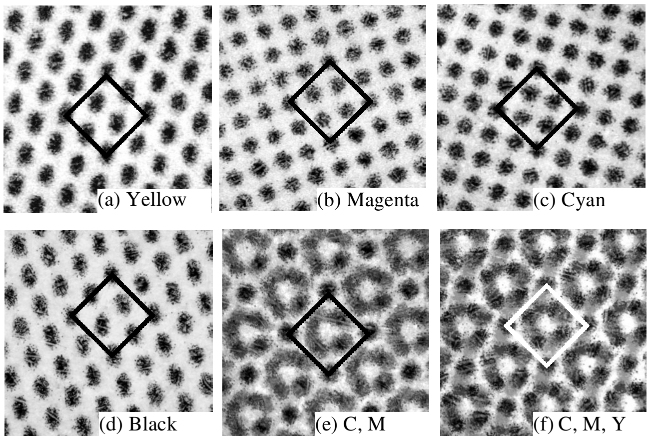


Figure 7. Enlargements of the ring coupling (180-type) screen

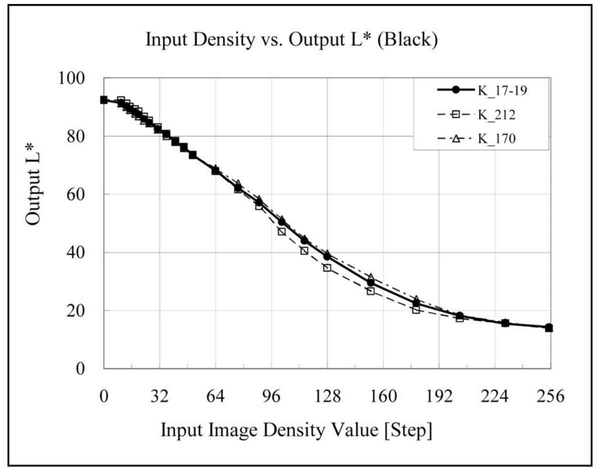
Tone Reproduction

Figure 8 shows tone reproduction curves of 180-type nonorthogonal and two conventional orthogonal screens. Figure 8 (a) shows characteristics of all density area, and Fig.8 (b) shows a part of highlight area. Here, the horizontal axis is the input density value of 0 to 255 step, and the vertical axis is lightness L*. K_17-19 shown in a straight line is a 180-type. K_212 is 212 lpi/45°, and K_170 is 170 lpi/45°. In comparison of all density area, gradient of K_17-19 is smoother than K_212. In highlight area, K_17-19 can reproduce a dot from a density region lower than K_212. Though the characteristic of K_17-19 is similar to K_170 very much, it shifts into the direction of K_212 a little. From these results, it is recognized that 180-type designed here has a property equivalent to about 180 lpi orthogonal screen.

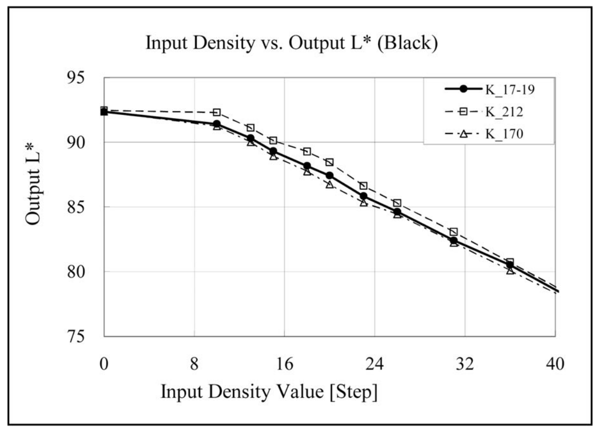
Conclusion

In conventional orthogonal screen, any color moiré between four colors could not be fully prevented, if high frequency screen like 300 lpi was not used. However, if "four color harmonics screen" shown in this paper is applied, any color moire except a basic pattern will not be generated in all combination of four colors. Therefore "four-color harmonics screen" is able to prevent a color moiré sufficiently, even if its screen-frequency is 150 to 200 lpi.

If a nonorthogonal screen is used, tone reproduction hardly differs from an orthogonal screen. Therefore, combining an orthogonal and a nonorthogonal is able to extend the flexibility of screen designing.



(a) All density area



(b) Highlight area

Figure 8. Tone reproduction curves of 180-type nonorthogonal and conventional orthogonal screens (K: Black)

References

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Biography

Akira Ishii received Master degree in Electronics Engineering from Shizuoka University in 1984. Since 1984, he has been working on full color Xerographic-printing. Now he works in R & D Center of Fuji Xerox. His work is primarily focused on full color digital halftoning. And he is a member of technology committee in the Imaging Society of Japan.