Restoration of Continuous Tone Images from Digital Color Halftone Images Based on Fourier Analysis of Local Areas

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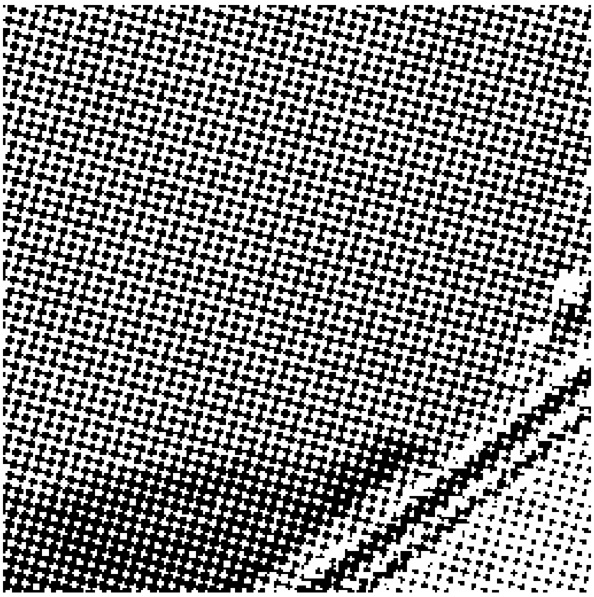
Abstract

A new algorithm that restores original continuous tone images from digital halftone dot images is proposed. The algorithm enables moiré free color proofing, even when the page image contains halftone pictures with unknown parameters – halftone dot period, direction, etc., or dot patterns are not regularly repeated. The proposed algorithm applies discrete Fourier transformation to each local area of an image, analyzes the halftone dot period, direction and offset, and restores the original continuous tone image. This local image analysis enables restoration of a page that consists of images screened using various directions and periods. Despite the use of local area division, the restored image does not suffer from block noise.

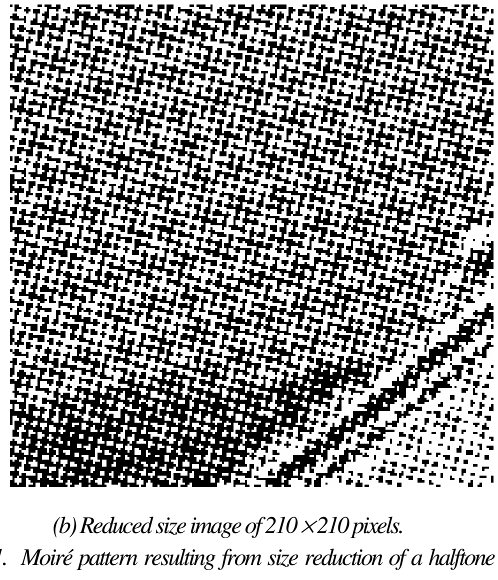
Introduction

Halftone dot films have conventionally been sent to printing factories with color proofs for color image printing. Recently, digital halftone dot image data generated by computers are sent directly to the factories via broadband networks. Color proofs are then generated from the digital data using color ink-jet printers and other similar devices. Because the dot resolution differs between the final printing and the proof printing, size reduction is normally required, and a moiré pattern often appears. Figure 1(b) shows an example of the moiré pattern that appears when the size of the original image (a) is reduced both horizontally and vertically to 83%. The moiré pattern appears based on the relation between the reduction rate and original halftone dot parameters (frequency and direction). As these parameters are unknown and uncontrollable from the viewpoint of a proofing system, the ideal processing is to automatically restore the original continuous tone image, and a halftoning process is applied again after resolution conversion and color management (Fig. 2). This paper discusses a new procedure for continuous tone image restoration (outlined with dotted lines in Fig. 2), which avoids the moiré pattern.

In restoring continuous tone images from halftone dot images, Fourier transformation has been conventionally applied to the whole image, and frequency peaks corresponding to the halftone dot pattern removed.[1] However, this algorithm has the following problems.



(a) Original image of 256×256 pixels.



(b) Reduced size image of 210 ×210 pixels.

Figure 1. Moiré pattern resulting from size reduction of a halftone dot image

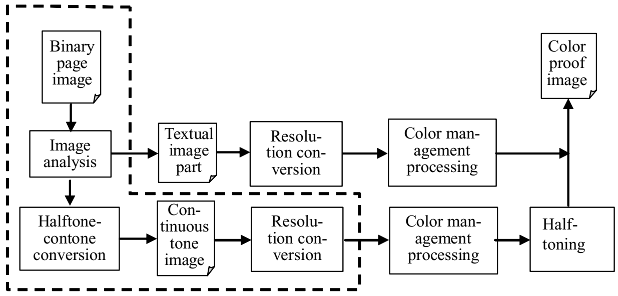


Figure 2. Ideal processing flow for color proofing.

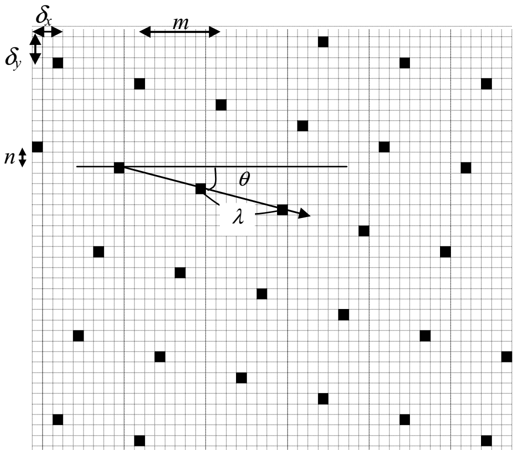


Figure 3. Analysis of a pattern within a local region.

(a) A printed page is composed of multiple components; typically picture parts and textual or line art parts. Continuous tone restoration is necessary only for picture parts. The picture components of the whole image must be recognized in advance.

(b) The halftone dot pattern of all pictures contained in an image must be the same. However, when a page consists of multiple pictures collected from various sources, each picture is often screened using parameters (dot period and direction) that are different from each other.

(c) The larger the image, the longer the total processing time required by Fourier transformation. The algorithm is not appropriate for large format images.

To solve these problems, our algorithm divides a page into small local regions. Fourier analysis is applied to these small regions to know local property of the image. Period and direction for each local region are detected, and a continuous tone value for every halftone dot is restored based on the property. Since the processing is independently applied to each local region, if the restored values are inaccurate, the restored image can suffer from block noise at region borders. Accurate restoration is necessary.

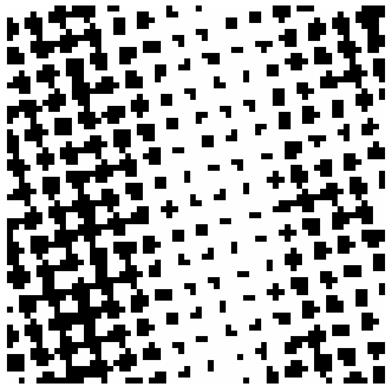


Figure 4. Example of a local region.

Local Region Analysis

Size of the local regions should be adequately determined, depending on image characteristics. The regions should be sufficiently large relative to the halftone dot period, while they should be sufficiently small relative to the size of layout components. To compromise on this trade-off, we divided binary halftone images into local regions of 64×64 pixels, and applied discrete Fourier transformation to these regions. With this size, about 6×6 dots are contained in a region, if the image resolution is 1000 dpi (dots per inch) and its halftone screen frequency is about 100 lpi (lines per inch). This is sufficient for halftone parameter estimation, and the region size on paper is as small as 2.5mm, which is acceptable for region classification.

The power for each wave number (kx, ky) is analyzed by Fourier transformation, and four parameters – angle θ, period λ and the offset values (δx, δy) – for the halftone dot pattern are computed. Figure 3 shows the relationship between the parameters and a halftone dot pattern.

Power peaks that correspond to the dot pattern should be detected at wave numbers in frequency domain. Peaks normally appear at wave numbers that correspond to the screen frequency. However, in case of natural images, peaks often appear at other wave numbers, depending on object textures in the images. In addition, low frequency peaks appear in many cases because of the small area division. This is because Fourier transformation postulates that a pattern in a small region is endlessly repeated, but this is not true in real images, and, for example, pixel values on the right border pixels of the region are not the same as those on the left border pixels. An example of a local region is shown in Fig.4 and a part of the Fourier power values for the region is shown in Table 1. Though a power peak should appear at the wave number position marked with ⬭, peaks are distributed in multiple wave numbers, and another wave number position marked with △ has a larger value. We used the following properties of halftone dot images to solve these problems.

(i) One power peak may not appear at one wave number only. Instead, a peak may be distributed in the surrounding wave numbers; their powers are evaluated as the sum of the powers for a group of wave numbers including the surrounding wave numbers. In this study, one peak is considered to be distributed in surrounding four wave numbers.

Table 1. Frourier power for the image in Fig. 4

ky\kx	0	1	2	3	4	5	6
0	2000000	160000	20000	500	2500	3800	800
1	890	2600	930	310	1400	610	230
2	1300	1500	120	230	810	1100	110
3	150	36	640	2000	370	800	580
4	34	280	1100	47	1800	55	250
5	130	890	390	81	3100	150	360
6	350	240	110	220	470	120	100
7	21	33	610	130	1300	380	8
8	120	27	420	820	1200	860	470
9	34	340	1000	790	810	330	100
10	65	140	60	190	3000	600	170
11	310	550	490	1500	6100	940	710
12	340	230	1100	2200	12000	2600	280
13	420	2400	7800	16000	100000	17000	1200
14	1100	2400	18000	20000	140000	19000	2900
15	150	330	1500	1900	17000	970	1100

(ii) Normal screen patterns are repeated in two orthogonal directions. That is, if there is a power peak at (kx, ky) in frequency domain, there are power peaks at (-kx, -ky), (ky, -kx) and (-ky, kx), too. Because discrete Fourier transformation for real images has outputs only in wave numbers where kx is positive, this property can be used for such verification that pairs of wave number groups which are mutually orthogonal and have similar sums of powers should be extracted. It is necessary to find two wave number groups, and, at least, eight peak wave numbers should be extracted after sorting them in the order of power.

(iii) The power of the peaks for higher order harmonics is sometimes higher than that for their basic wave numbers. In these cases, we want to use the basic wave numbers. For this purpose, too, sufficient number of high power peak groups must be extracted beforehand. To detect such relation, we check every peak to see, whether the peak can be a higher order harmonic of another peak, and, if it is true, the peak for the basic wave number is used for further processing.

The above described procedure necessitates extraction of power peak groups and sorting in order of their power. Twenty peak wave numbers are extracted in this study for the orthogonality verification and the higher order harmonics removal. Period λ and direction angle θ are easily calculated from the obtained wave number of the Fourier power peak (kx, ky). The offset (δx, δy) is calculated from the Fourier phase. Fourier transformation is done using the discrete version of Eq. (1), and if we define the pattern phase by Eq. (2), α and (δx, δy) can be computed by Eqs. (3) and (4), respectively.

$$F(k) = \int_0^1 f(x) e^{-2\pi jkx} dx \qquad (1)$$

$$f(x) = \sin(2\pi kx + \alpha) \qquad (2)$$

$$\tan\alpha = -\frac{\mathrm{Re}(F(k))}{\mathrm{Im}(F(k))} \qquad (3)$$

$$\delta x = -\frac{\lambda \alpha k_x}{2\pi\sqrt{k_x^2 + k_y^2}}, \quad \delta y = -\frac{\lambda \alpha k_y}{2\pi\sqrt{k_x^2 + k_y^2}} \qquad (4)$$

It was confirmed by our experiments, that these values are stably computed, independently of the relative position of local region. The offset value does not necessarily define the absolute center position of a halftone dot. However, in our application, it is not important to know the absolute center position. It is sufficient to know some position that is accurate in phase with respect to the halftone dot center positions.

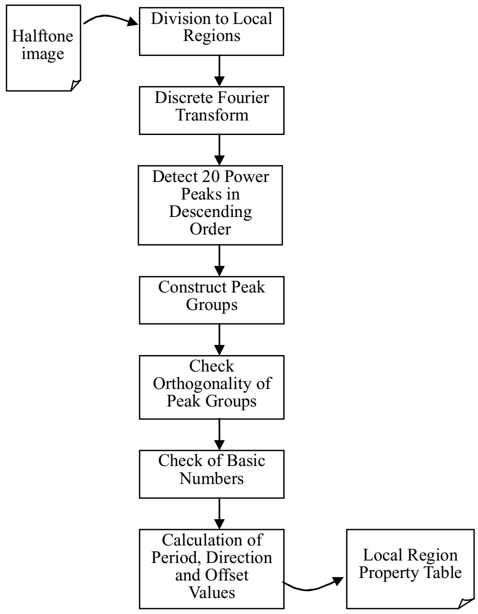


Figure 5. Local area analysis processing.

If appropriate peaks are not detected for a region, the region is regarded as a textual or a line art region. Figure 5 shows the flow of the local region analysis. Analysis results are stored as a local region property table.

Restroration of Continuous Tone Pixel Values

Restoration processing restores a continuous tone value for every halftone dot in the local region, using the original halftone image and the local region property table. A continuous tone value is directly restored, counting black pixels in a halftone unit area. If the halftone pattern is simple as shown in Fig. 3, Eqs. (5) and (6) hold between the pattern period (*m,n*) and (λ, θ) obtained.

$$m^2 + n^2 = \lambda^2 \qquad (5)$$

$$\tan\theta = \frac{n}{m} \qquad (6)$$

Hence, the continuous tone value is the mean value in a square which is obtained by connecting black pixels in Fig. 3. In the case where θ is not 0 or $\pi/2$, the border of the square lies obliquely, and calculation may be complicated. Our current algorithm computes a mean value for λ^2 pixels surrounding the 'center position', without considering the square. The center positions are obtained from the parameters θ, λ and (δx, δy), marked with × in Fig. 6, and, the values of λ^2 pixels around the position are averaged. This simple algorithm can be extended to the case where the halftone dot area size is not constant and the center positions of dots lie between pixels, without major change. This extension is discussed in the next section.

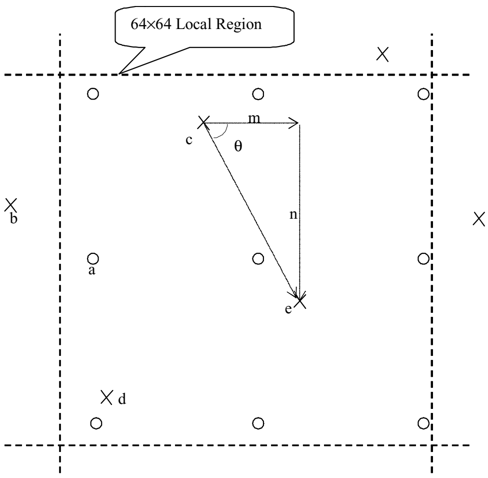


Figure 6. Positions where continuous tone values must be obtained (o), and positions of surrounding centers of halftone dot areas (×).

The output of color proofing is a reduced-size image, and the continuous tone image values must be calculated at the positions regularly sampled in the x and y directions, as depicted with circles in Fig. 6. The continuous tone output value for 'a', for example, is obtained by interpolating four values for the centers of the surrounding halftone dots ('b', 'c', 'd', and 'e').

Processing for Irregular Dot Patterns

The restoration can be carried out without problem if the halftone pattern is simple and the unit area is regularly repeated as depicted in Fig. 3. However, digital halftone color images are often generated with a more complicated algorithm. Halftone dot patterns for cyan, magenta, and black inks are conventionally generated with the same period but in three different orientations, with angles rotated 30° from each other. However, these patterns cannot be accurately produced by digital halftone generation. Because of this, irregular halftone dot regions, with areas that are similar but not exactly the same, are often generated to avoid moiré patterns [2].

Suppose that we need patterns in three directions – 15°, 45° and 75°, and the direction for 15° should be very accurate to avoid interference with the 45° pattern. Directions are defined by (m,n), and Fig. 7 shows errors of possible directions in the angles. An accurate 15° pattern can be obtained if λ = 16, while it is impossible if λ = 8, if we use simple regular patterns. However, this is globally possible if we divide the square of λ = 16 into four dot areas that have not the same sizes.

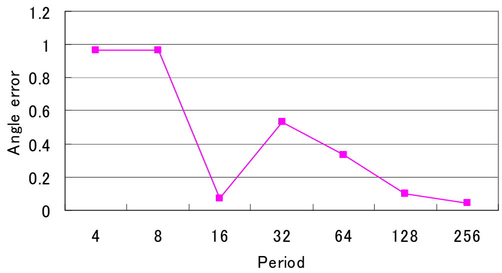


Figure 7. Relation between halftone dot period and angle error in the case of θ=15°.

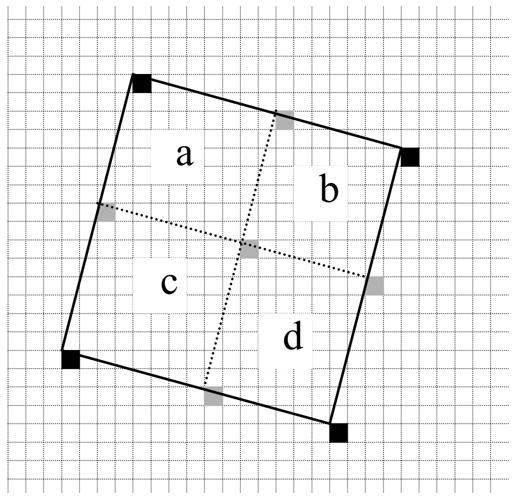


Figure 8. Subdivision of a basic local area.

Figure 8 shows an example. Repetition parameters (m,n) are (15,4), and an area includes 241 pixels. Dividing the area into four sub areas – a, b, c and d –, four halftone dots are generated. The halftone dot area sizes are 59, 54, 68 and 60, and are not equal to each other. The continuous tone restoration described in the previous section often fails for halftone images generated with such an irregular dot pattern. Resulting continuous tone images become inhomogeneous, since the centers of the dots are not regularly located and relative positions surrounding λ^2 pixels deviate. To overcome this problem, continuous tone values are obtained not only for the center position of a halftone dot but also for its neighboring positions, and then their mean value is used as the output value. Though this is a kind of blurring and blurs the image, the effect does not come out, if the number of used neighbors is not too large.

Experimental Results

Figure 9 shows the result of our algorithm for an image that has been generated using an irregular dot pattern. Figure 9 (a) shows the result when using only one continuous tone value for a dot, while (b) shows the result of using the mean values of multiple positions, which produces a much smoother restoration of the sky area without moiré patterns. It should also be noted that the resulting image does not suffer from the block noise that normally appears when local area division is included in the algorithm.

As this image has few periodic patterns, no interference with the halftoning process that generates a proof image (Fig.2) would come out. We can apply any halftone generation algorithm to the restored image. Figure 9(c) shows an example of the proof image with an angle and a period other than those of the original halftone image. It is easy to select a halftone dot pattern that does not cause a moiré pattern.

Conclusion

We have developed a new algorithm to restore continuous tone images from digital halftone dot images. This algorithm, at first, analyzes local regions of a halftone image to obtain period, direction and offset values, and then directly calculates the continuous tone values of each halftone dot depending on the local properties. Hence, even if a page has been composed of multiple halftone pictures generated using different dot patterns, it is possible to restore continuous tone images for individual pictures with pertinent parameters, in principle.

Though the simple algorithm fails when the digital halftone image has been generated using irregular dot patterns, high quality restoration can be achieved by restoring continuous tone values also for neighboring pixels and averaging the continuous tone values. In addition, it is also possible to leave textual and line art parts unprocessed. However, this function can be discussed in a separate context, and a combined use of other algorithms as shown in Ref. [3] is also possible.

References

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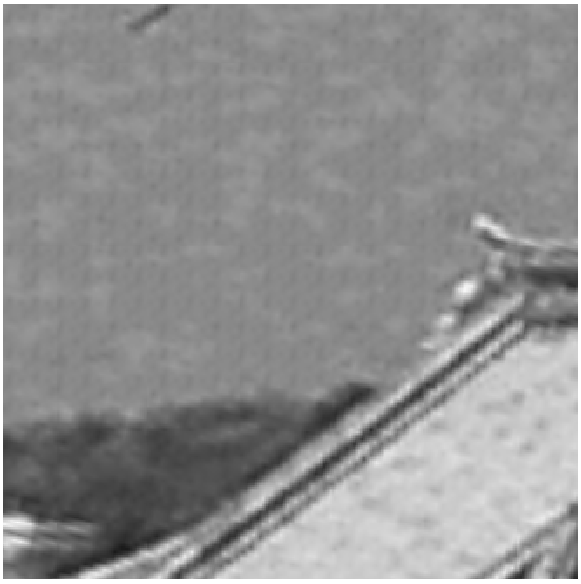
Biographies

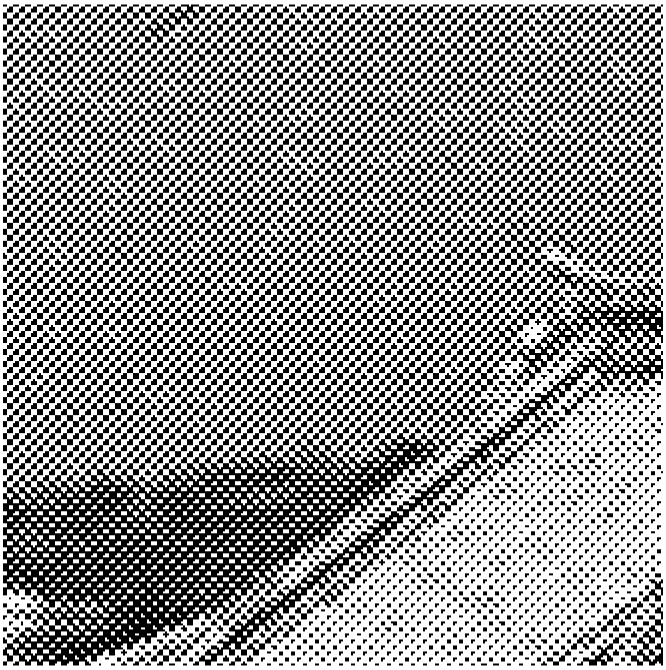
Johji Tajima graduated from the Faculty of Science, the University of Tokyo, in 1971 and received a doctorate in 1990. From 1971 to 2003, he was a research member of NEC Corporation and was engaged in research on image processing and pattern analysis, especially color image processing and 3D vision. In 2003, he became a professor of the Graduate School of Natural Sciences, Nagoya City University. Prof. Tajima is a member of the IEICE, IIEEJ, and the Information Processing Society of Japan (IPSJ). He is a fellow of IAPR.

Masato Tsukada is a research scientist in the Media and Information Research Laboratories, NEC Corporation. He received the BS degree and MS degree in computer science from Tsukuba University, in 1989 and 1991, respectively. Since joining NEC Corporation in 1991, he has been engaged in research on color vision, color image processing and color reproduction. He was awarded the best paper award by the Institute of Image Electronics Engineers of Japan (IIEEJ) in 1998. He is a member of the Information Processing Society of Japan (IPSJ).

(a) Restoration using one value.



(b) Restoration using multiple values.



(c) Example of proof image (result of halftone generation).

Figure 9. Continuous tone images restored from an irregular halftone dot image (Fig.1).