Study on the Phenomena of Moiré Fringe in Digital Halftoning

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Abstract

The AM halftoning is the most commonly used digital halftoning method in current color image printing. In its application, the most key issue is to select the appropriate screen angle to avoid producing Moiré fringe. As we all know, the strength of the Moiré fringe varies with the change of overlap angle of two halftone image. Its rules follow the Tollennaar formula. However, in our research, we find that the Tollennar Moiré formula is correct only when screening line n_1 equals to screening line n_2. When the difference between n_1 and n_2 is much, the Moiré curve based on the observation data does not accord with the Tollenaar Moiré formula, many new phenomena and rules are found out. Such as, when the overlap angle is near to 0°, the strength value of Moiré fringe is not divergent but convergent. We also find out that when the value of n_1 is bigger than n_2 to 15 and the overlap screen angles from 20° to 30°, the Moiré fringe becomes the weakest. By researching the above phenomena and rules, many special issues in halftone image duplication can be solved.

Introduction

The screen dot is the basis of composing printing image and the basic cell of expressing the color image tone. It transfers the tone of image. In the duplication of color continuous original, transferring the color and tone of original to the printed matter as verily as possible is the core of success of image duplication. After long researches and practices of human being, the modern color image duplication technology which adopts screen dot to print forms [1].

The AM halftoning is the most commonly used halftoning method in current color image printing. In its application, the most key issue is to select the appropriate screen angle to avoid producing Moiré Fringe. As we all know, when any two regular halftone images are overlapped, the Moiré Fringe will occur. The strength of the Moiré Fringe varies with the change of overlap angle of two halftone image. Its rules follow the Tollennaar formula. According to this formula, when two screens with the same screening line number are overlapped and the overlap angle θ varies between 0°and 45°, the curve of space Pm(Pm=1/Nm) of Moiré Fringe can be calculated[2] . When overlap angle θ is 45°, the strength of Moiré Fringe is the weakest. However, in our research, we find that the Tollennar Moiré Fringe formula is sound only when two screening line numbers are equal or near. When the difference between two screening line numbers is enough much, the Moiré curve drawn based on the observation data does not comply with the Tollenaar Moiré Fringe formula. And when the Moiré Fringe is the weakest, the overlap angle is not near to 45°, but within the range from 20° to 30°. In this paper, this phenomenon is researched and summarized and some new conclusions are drawn.

Moiré Fringe and Tollenaar formulation

AM Halftoning produces a kind of regular dot. When two halftone screens are overlapped, the Moiré Fringe will occur as following figure 1.

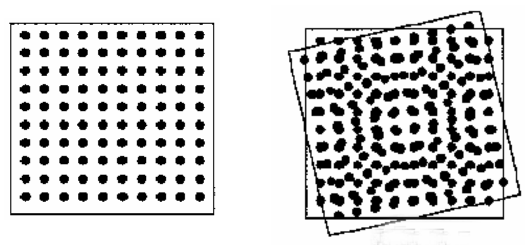

Figure1. *Halftoning image before and after overlapping*

If p_1, p_2 are the spaces of two screens individually, PM is the space to Moiré Fringe and θ is the overlap angle of two screens, then the Moiré Fringe can be expressed by following Tollenaar formula (1).

$$P_M = \pm \frac{P_1 \cdot P_2}{\sqrt{P_1^2 + P_2^2 - 2P_1P_2\cos\theta}} \tag{1}$$

In this formula, When P1cosθ□P2□the PM is positive. Otherwise, it is negative.

According to formula (1), when the overlap angle ranges from 0° to 45°, we can draw the space PM of Moiré Fringe curve O as following figure 2. From the curve O, we can see that when two halftone images with the same screening line are overlapped, the strength of the Moiré Fringe varies with the overlap angle θ from the infinite, the huge, the big, a little noise to the vision to the minimization at the point where the θ is 45°.

But, in our research, it finds that only when the p1 is equal or near to p2, the Tollenaar formula is sound. When the difference between p1 and p2 is enough much, the Moiré Fringe curve based on the observation data does not abide by Tollenaar formula[3].

Research into the Moiré Fringe in Frequency Conversion Amplitude Modulation (FCAM) Halftoning

What is researched in this paper is still the method based on AM halftoning. We try to change the screening line numbers and overlap angle of two screens and observe the phenomenon and rules of the Moiré Fringe. Here, we temporally call this halftoning method frequency conversion amplitude modulation (FCAM) halftoning [4].

In order to observe the experimental result clearly, we take the Moiré Fringe, which occurs when two halftone screens are overlap, as an example. Here, we temporarily don't take the influences of the Moiré Fringe shape and secondary Moiré Fringe into consideration. In this experiment, we judge the strength of Moiré Fringe by the space of primary Moiré Fringe. Evidently, in the visual field, the bigger the space of Moiré Fringe is, the much more easily the Moiré Fringe is observed and the more heavily it influences the human vision.

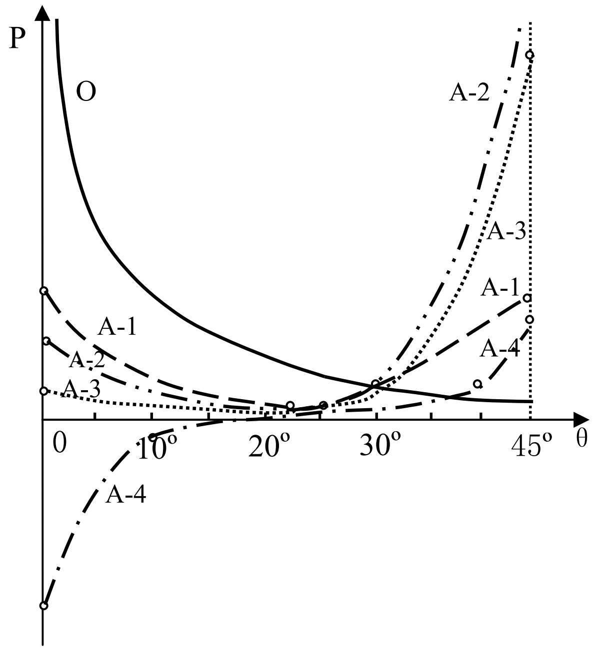

Figure2. The trend of Moiré Fringe.

In order to make a comparison easily, in figure 2, first, an relation curve O between the strength of Moiré Fringe P and overlap angle θ is drawn when two screens with the same screening line number 175 lpi are overlapped.

Experiment 1: we use two screens, one is 175 lpi; the other is 150lpi. So the difference of screening line number is 25lpi. If the overlap angle is within 0º- 45º, the strength of Moiré Fringe is the curve A-1 in figure 2.

Experiment 2: we use two screens, one is 175 lpi; the other is 133lpi. So the difference of screening line number is 42lpi. When the overlap angle is within 0º-45º, the strength of Moiré Fringe is the curve A-2 in figure 2.

Experiment 3: we use two screens, one is 175 lpi; the other is 120lpi. So the difference of screening line number is 55lpi. When the overlap angle is within 0º-45º, the strength of Moiré Fringe is the curve A-3 in figure 2.

Experiment 4: we use two screens, one is 175 lpi; the other is 100lpi. So the difference of screening line number is 75lpi. When the overlap angle is within 0º-45º, the strength of Moiré Fringe is the curve A-4 in figure 2.

The analysis and discussion of experimental result

From the aforementioned experiments, we find the phenomenon and the strength of Moiré Fringe, which are produced when one of two screening line numbers changes and the overlap angle ranges from 0º to 45º, are much different with those produced when two screening line numbers are same and the overlap angle range is same. We can find some rules and utilize them to solve the problems in the image halftoning duplication.

In FCAM halftoning, the change of the Moiré Fringe can be summarized as following:

(1) Applying FCAM halftoning technique, when the overlap angle of two screens approximates to angle 0º, the Moiré Fringe is convergent. This is different with the same screening line number halftoning. When two screens with the same screening line number are overlapped, from angle 0º to a certain small angle, the Moiré Fringe is from infinite, immense to very big. The process changes rapidly. But applying FCAM halftoning technique, when two screens are overlapped, the Moiré Fringe is stable when the screen angle is near to 0º. As the angle increases, the Moiré Fringe changes slowly and has a fixed initial value which we call W_0. If the halftoning frequency and the difference S of halftoning frequency are different, the W_0 is also different. It can be expressed by figure 3.

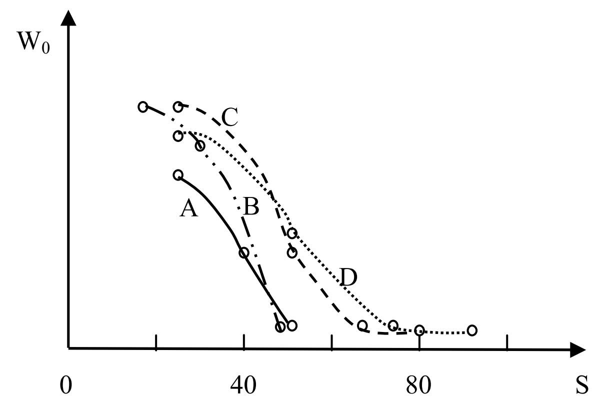

Figure3. The relation between the strength of Moiré Fringe and the halftoning frequency difference.

(2) When the halftoning frequency of one screen is fixed, within a certain range, the larger the difference between the fixed frequency and the variable frequency is, the smaller the Moiré Fringe is. When the difference of halftoning frequency is up to a certain value, the W_0 is up to the minimum. Then the Moiré Fringe is invisible, so it can be avoided. But when W_0 is up to the minimum, at this time if the difference of halftoning frequency increases continually, a dark Moiré Fringe will occur where the overlap angle is near to 0º. Compared with common Moiré Fringe, the dark Moiré Fringe is contrary in brightness and its strength is very weak. But as the overlap angle increases to 45º, it will become invisible.

(3) The halftoning frequency difference which makes the W_0 minimum also varies with the screening line numbers of two screens. From the experiment we can see that when the screening line number of fixed screen increases, the halftoning frequency difference which makes the Moiré Fringe invisible also increases where the overlap angle is 0º. The table 1 summarizes the relative experimental data. From it, we can see the change trend.

Table 1 The relationship between the fixed Halftoning frequency and Halftoning frequency difference

Fixed Halftoning frequency (lpi)	150	175	200	225
Halftoning frequency difference (lpi)	50	55	67-80	75-92

From the experimental result we can draw following conclusions:

Supposing the fixed screen is P_1 whose screening line number is n_1 , when the screening line number of variable screen P_2 decreases to n_2 ,namely, the difference of two screening line numbers is $S_1(n_1- n_2= S_1)$, the Moiré Fringe is up to the minimum. When the n_1 is fixed, the screening line number of variable screen P_2 is up to n_3, namely, the difference of two screening line number is $S_2(n_3- n_1= S_2)$, the Moiré Fringe is also up to the minimum.

The following equation should exist:

$$\frac{S_1}{N_2} = \frac{S_2}{N_1} \qquad (2)$$

(4) The CFAM Halftoning is different with the same line number AM Halftoning. When the Moiré Fringe is up to the minimum, the overlap angle is not 45º but ranges between 20º and 30º.

(5) Adopting the CFAM Halftoning, when two screens are overlapped, the Moiré Fringe is up to the maximum at the overlap angle 45º.

(6) When the Halftoning frequency is up to a special value, the Moiré Fringe can be avoided in a certain overlap angle scale or the Moiré Fringe can be controlled in a comparatively small scale, such as the curve A-4 in the figure 2.

(7) The strength of Moiré Fringe produced in FCAM Halftoning is very weak. Especially, when the screening line number is up to a certain value, the strength of Moiré Fringe is very weak at the screen angle 0º.

From the curve A-3 in figure 2, we can see that the Moiré Fringe is not evident when the overlap angle ranges from 0º to 30º. It can solve the problem that the strength of Moiré Fringe is comparatively strong in curve O when the overlap angle ranges from 0º to 30º. When the overlap angle is larger than 30º, the Moiré Fringe becomes strong in curve a-3 while it is not evident in curve O. So, if they are combined to be applied, there is perspective to solve many problems in the AM Halftoning.

According to the characteristics and rules of FCAM Halftoning, the following principles should be abided by in the application of FCAM Halftoning.

- We should not apply the overlap angle which is near 45º as possible. Because the Moiré Fringe in all FCAM Halftoning is up to the maximum when the overlap angle is 45º (except the difference of Halftoning frequency is very large).
- The difference of Halftoning frequency should not be too large. First, the difference of frequency means the leap of dot frequency. The too large difference of frequency will badly influence the quality of image duplication. Secondly, when it is larger than a certain value, reversely, a darker and stronger Moiré Fringe will occur when the overlap angle is near to 0º. Compared with the common Moiré Fringe, this Moiré Fringe is reverse in brightness.
- We should apply the overlap angle range from 20º to 30º as possible. In all FCAM Halftoning, the strength of Moiré Fringe is up to the minimum in this overlap angle range.

Conclusions

From the research in this paper, it can be seen that in the AM Halftoning, the long used Tollenaar formula is only for the situation when the two screening line numbers are equal or near to each other. When the difference of two screening line numbers is up to a certain value, the practical Moiré Fringe will not follow the Tollenaar formula. For example, in our experiment, when the difference of screening line number is larger than 15 lpi, it does not comply with the Tollennar formula. This is an important discovery. This paper researches into this new phenomenon and summarizes several rules as above mentioned

The phenomenon of Moiré Fringe discovered and FCAM Halftoning method brought forward in this paper can be applied in some special fields of image processing and duplication. Especially, it provides much more technical selections in color image printing. For example, the combination of common AM Halftoning and FCAM Halftoning discussed in this paper can solve the limitation of four screen angles in AM Halftoning and achieve the six-color or sever-color HF color printing [5].

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