Research on LCD Moiré Based on Fast Fourier Transform

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ABSTRACT

This article reports a research method of LCD moiré based on Fast Fourier Transform (FFT). We use programmable software to build a complete moiré simulation model, and established an evaluation system. This method has been verified to have high accuracy in moiré simulation, and because it is based on image processing, the moiré results can be quickly obtained, thus the design efficiency can be greatly improved.

1 Introduction

Moiré fringes are periodic fringes produced by the superposition of two or more periodic structures. We know that LCD is mainly composed of display panel and backlight module, the pixel of the display panel is a periodic structure, and the brightness enhancement film (BEF) or the privacy film (for privacy display) in the backlight is also a periodic structure, so the display panel and the backlight are prone to have frequency interference, and resulting in moiré fringes. Moiré will affect the display quality and lower the user experience. We know that adjusting the angle of the periodic structure is an effective way to reduce moiré, so designers usually place the panel on the backlight, rotating the backlight at different angles and watching the visual effects, and finally choose the best angle. However, this method is labor-intensive, completely subjective, and cannot be quantified.

In this article, we have studied the mechanism of LCD moiré. Through MATLAB programming, images of display panel and backlight are automatically generated, and then we superimpose the two images to get an LCD image. By performing FFT on the LCD image, we get its Fourier spectrum. By filtering this spectrum, and analyzing the filtered spectrum data, the degree of moiré at different angles can be quickly judged, such that we can effectively identify moiré risk.

2 The theory of moiré

Firstly, we analyze how the moiré is formed with the simplest two one-dimensional (1D) gratings structure. Grating A (Fig. 1(a)) and Grating B (Fig. 1(b)) are two one-dimensional gratings. As shown in Formulas (1-3), $f(T_1)$ is the function of Grating A, $f(T_2)$ is the function of Grating B, and the composite structure $f(T)$ is obtained by multiplying Grating A and Grating B. The functions $f(T)$ can be divided into the following four items, where the first item is a constant item, the second item includes information of Grating A, the third item includes information of Grating B, and the fourth item is a new mathematic expression, which includes the moiré information, as we can see a clear moiré in Fig. 1(c).

$$f(T_1) = \frac{a_{01}}{2} + \sum_{n=1}^{\infty}\left[cos\left(n\frac{2\pi}{P_1}x\right)\right] \tag{1}$$

$$f(T_2) = \frac{a_{02}}{2} + \sum_{m=1}^{\infty} a_m \cos\left[m\frac{2\pi}{P_2}(xcos\theta - ysin\theta)\right] \tag{2}$$

$$\begin{aligned} f(T) &= f(T_1) * f(T_2) \\ &= \frac{a_{01}}{2} * \frac{a_{02}}{2} + \frac{a_{02}}{2} * \sum_{n=1}^{\infty}\left[cos\left(n\frac{2\pi}{P_1}x\right)\right] \\ &+ \frac{a_{01}}{2} * \sum_{m=1}^{\infty} a_m \cos\left[m\frac{2\pi}{P_2}(xcos\theta - ysin\theta)\right] \\ &+ \sum_{n=1}^{\infty}\left[cos\left(n\frac{2\pi}{P_1}x\right)\right] * \sum_{m=1}^{\infty} a_m \cos\left[m\frac{2\pi}{P_2}(xcos\theta - ysin\theta)\right] \end{aligned} \tag{3}$$

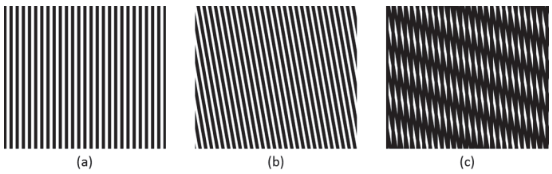


Fig. 1 (a) Grating A (b) Grating B (c) Moiré of Grating A and B

Next, we studied the display panel and backlight of the LCD which are both periodic structures. They are also prone to have frequency interference, and resulting in moiré issue as shown in Fig.2. The theory is consistent with two 1D gratings, the only difference is that the display panel is mostly 2D grating, so it's more complicated.

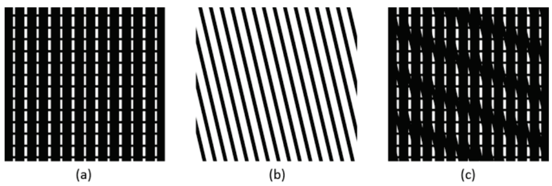


Fig. 2 (a) Image of sub pixel (b) Image of BEF (c) LCD moiré

3 Application of FFT in fringe analysis

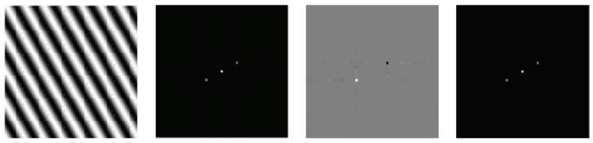
Because it is difficult to directly analyze the interference of the two 2D gratings in the spatial domain, the Fourier Transform (FT) is usually used. Through processing and analyzing the FT spectrum, the problem becomes easier. This is an important reason why FFT is widely used in digital signal processing.

Formulas 4~6 show the basic definition of 2D Fourier Transform. Fig.3 (b), (c) and (d) shows the real part, imaginary part and modulus of Fourier Transform respectively of the fringe image shown in Fig.3 (a). From Fig.3(d), we can see a pair of center-symmetric bright spots, its connection direction is perpendicular to the stripe direction. If the bright spot is closer to the center, the fringe frequency is lower, and vice versa.

$$f(u,v) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)\, e^{-j2\pi(ux+vy)} dxdy \quad (4)$$

$$f(u,v) = R_e(u,v) + jI_m(u,v) \quad (5)$$

$$|F(u,v)| = \sqrt{R_e^2(u,v) + I_m^2(u,v)} \quad (6)$$



(a) (b) (c) (d)

Fig. 3 (a) Stripe image (b) Real part of the Fourier spectrum (c) Imaginary part of the Fourier spectrum (d) Modulus of the Fourier spectrum

4 Human Visual Characteristics

Before processing the Fourier spectral data, it is very important to determine an appropriate filter function, which must match the characteristics of the human eye. Scientists have done a lot of research on human eye system (HVS), and have established multiple sets of visual models, such as Gaussian model, exponential model, Barten model and composite model. Among these models, Gaussian and exponential model are both low-pass filters, while Barten and composite are band-pass filters, which are more in line with the actual human eye characteristics. And because the parameters of the Barten model are relatively simple and the operation efficiency is high, this paper uses the Barten model to analyze the FFT data. The Barten model is given by Formula (7). By inputting the LCD brightness as 450nit, we get the resulting curve like Fig.4: we can find that the human eye has the highest sensitivity around 3~4cyc/deg. Then we replace the angular frequency with the spatial frequency, with relationship shown in formula (8). And then we set the observation distance to 250mm (distance of distinct vision), and finally we obtain the filter matrix as shown in Fig.5.

$$MTF = a * f * e^{-bf}[1 + c * e^{bf}]^{1/2} \quad (7)$$

$$a = 440 * (1 + 0.7/L)^{-0.2}, b = 0.30 * (1 + 100/L)^{0.15}, c = 0.06$$

$$F_{angular} = D * F_{sptial} * \pi/180 \quad (8)$$

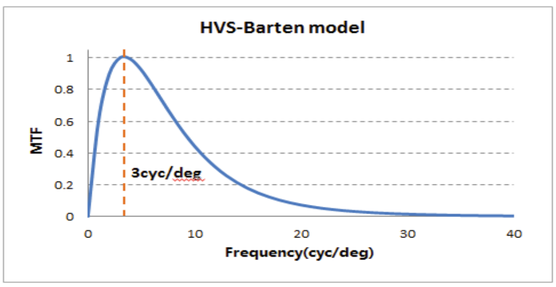


Fig. 4 HVS-Barten model

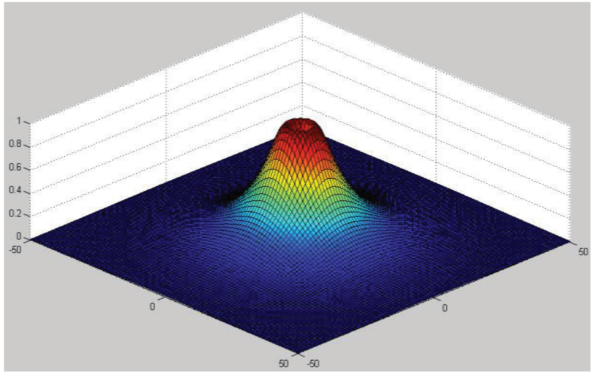


Fig. 5 Filter matrix based on Barten model

The filtering process takes into account only the influence of frequency, but to determine whether the moiré is visible or not, it is also necessary to evaluate the contrast of the stripes. Fig.6 shows the sensitivity curve of the human eye at different frequencies and contrasts. Similarly, we can see that the human eye can distinguish the lowest contrast when the frequency is 3~4cyc/de. The value of the bright spot in the filtered spectrum as shown in Fig.3 is positively correlated with the contrast of the corresponding fringe, so the contrast can be analyzed by studying the value of the filtered spectrum.

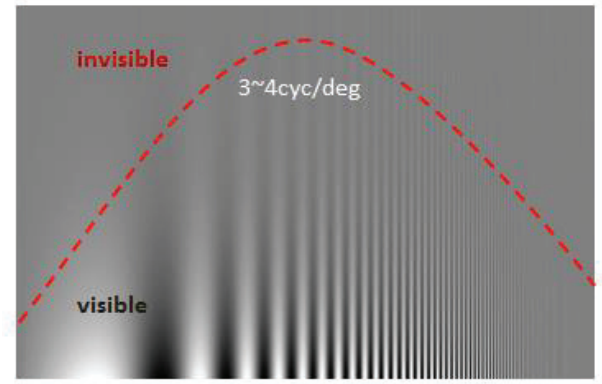


Fig. 6 The sensitivity of the human eye to stripes

5 Moiré simulation architecture

MATLAB software is very advantageous in calculating Fourier transform. Based on the above theory, we use MATLAB to build a complete simulation model as shown in Fig. 7. It is mainly divided into the following steps: 1. Input the pixel and backlight film parameters, 2. Generate pixel images and backlight film images, 3. Multiply the pixel image and the backlight film image, 4. Perform fast Fourier transform on the composite image, 5. Filter according to Barten model, 6. Output the value of the bright spot in the filtered spectrum and its location, and calculate the moiré angle and direction, 7. Inverse Fourier transform to obtain the moiré image, 8. Modify the Angle of backlight film material and repeat the above steps. 9. Comprehensively analyze the moiré image and the spectral value for evaluation. Through this simulation model, the moiré simulation result can be quickly output.

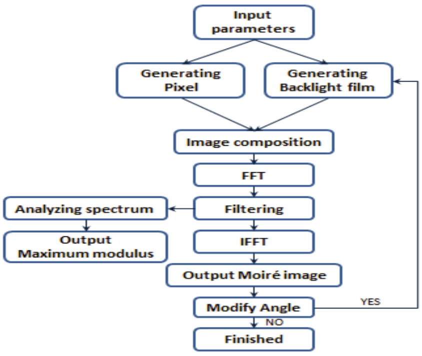


Fig. 7 Moiré Simulation Architecture Diagram

6 Results

Based on the above simulation model, we used a 6.7 inch display panel with PPI=391 and a 3M model of 4+ privacy film to do a full-angle (θ=1~180°, step 1°) moiré simulation. Since the human eye is most sensitive to green, we chose to analyze the moiré of green screen. Fig. 8(a) and (b) are the actual images of the display screen and privacy film, Fig. 8(c) and (d) are the images of the display screen and privacy film automatically generated according to the input parameters. The actual generated image size is 5*5mm and the resolution is 2048*2048. The simulation is run on an ordinary laptop, and the total time is 25min.

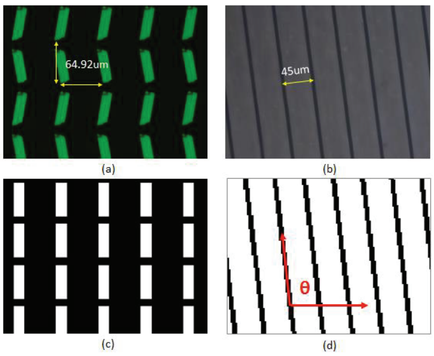


Fig. 8 (a) OM image of green Screen (b) OM of 3M-4+ privacy Film (c) Generated display image (d) Generated privacy film Image

Fig. 9 shows the final simulation results. The degree of moiré at different privacy film θ angles is different. θ is the best near 115° and 170°, and the moiré is the worst near 90° and 135°. And because the pixels of the display screen are symmetrical, the simulation results are symmetrical around 90°.

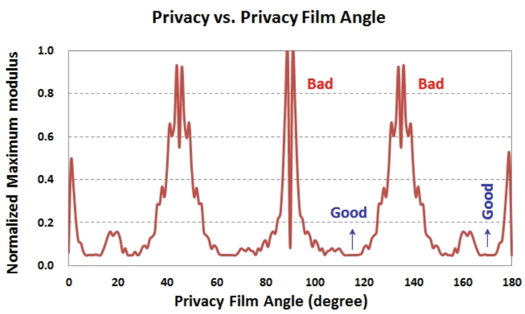


Fig. 9 Moiré simulation result

Fig. 10 shows the simulated moiré spectrum, the simulated moiré image and the actual captured moiré image of θ=115° and θ=138°. It can be seen that these two sets of result match well.

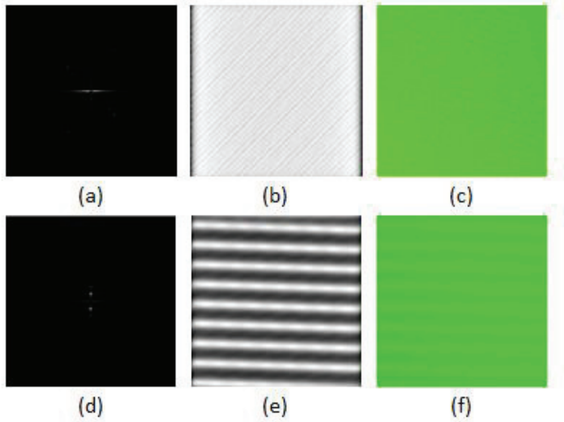


Fig. 10 (a) Spectrogram of θ=115° (b) Simulated moiré image of θ=115° (c) Actual image of θ=115° (d) Spectrogram of θ =138° (e) Simulated moiré image of θ=138° (f) Actual image of θ=138°

7 Discussion

This analysis method is completely based on image processing, so in the process of image superposition, the two periodic structures are directly multiplied. But in practice, because the unit sizes of the display screen and the privacy film are relatively small, there will be a certain diffraction effect, which will bring some errors. In addition, this model has great advantages in simulating moiré at on-axis viewing angle of LCD. For moiré at oblique viewing angle, more factors need to be considered.

8 Conclusions

This paper realized the LCD moiré simulation and evaluation based on the two-dimensional Fourier transform of the image. It has been verified that it has high accuracy and fast simulation efficiency, and can be used to guide the LCD design work. The results of this paper are not limited to the moiré of LCD, any form of moiré can be analyzed by this method only by adjusting the input interference image unit theoretically.

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