The Driving System of Electrowetting Display Based on Multi-Gray Dynamic Symmetry Driving Waveform

Shanling Lin[1,2], Mingyong Qian[1,2], Zhixian Lin[1,2], Tailiang Guo[1,2]

[1]Institute of Optlelectronic Display, National & Local United Engineering Lab of Flat Panel Display Technology, Fuzhou University, Fuzhou 350116, China;
[2]College of Physics and Telecommunication Engineering, Fuzhou University, Fuzhou 350116, China
*Corresponding author. E-mail addresses: lzx2005000@163.com (Zhixian Lin).
Keywords: Electrowetting display, driving system, driving waveform

ABSTRACT

In order to play video in real time of electrowetting display, a display driving system which included a DVI video codec system and FPGA timing control system was designed. The paper also proposed an improved multi-gray scales dynamic symmetrical driving waveform, which improved the oil-splitting phenomenon and suppressed the charge-trapping phenomenon while increasing the gray level.

1 INTRODUCTION

Since the invention of electrowetting display (EWD) technology in 2003[1], EWD has gradually developed. Compared with the traditional electrophoretic display (EPD), the EWD has a fast response, which enables dynamic video playback. In addition, the EWD is a reflective display that doesn't require a backlight which make a low power consumption.[2] Although great progress has been made in the study of electrowetting, many problems remain unresolved, such as charge trapping,[3] oil splitting, bistable instability, etc..[4]

In this paper, we designed an EWD driving system, which realizes multi-gray video playback in real time. And we proposed a new multi-gray dynamic symmetrical driving waveform, which effectively suppresses oil splitting and charge trapping phenomenon while increasing the gray scale.

2 THE DRIVING SYSTEM

2.1 The structure of EWD driving system

The structure of EWD driving system is shown in Fig.1. The video codec system is implemented by DVI link, which is mainly responsible for obtaining high-quality signal sources, image codec and data transmitting with multiple resolutions. As the receiving end of the data, the DVI decoding chip decodes the received image data and sends it to the FPGA control system through the LVDS interface. The FPGA control system is responsible for reading, writing and buffering video data, as well as timing control, which realizes the real-time dynamic playback. In this paper, the monochrome EWD panel is used to test the whole driving system, which the resolution is 1024×768. In order to play video without flicker, the refresh ratio is set as 30Hz.

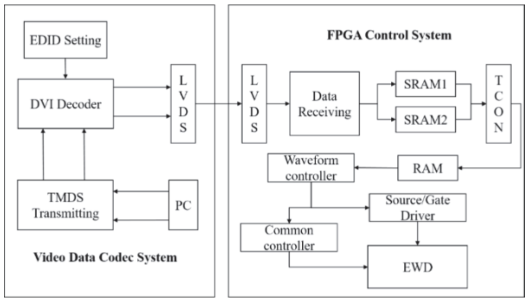


Fig. 1 The structure of EWD driving system

2.2 The bilinear interpolation algorithm

To adapt to the resolution of the PC and EWD, the driving system uses a bilinear interpolation algorithm to scale the received data. The bilinear interpolation algorithm uses second-order Lagrangian interpolation to calculate the pixel points. The algorithm is based on two interpolations in the vertical direction and then one interpolation in the horizontal direction to obtain the final pixel values. As shown in Fig.2, find the four pixel points Q_{11}, Q_{12}, Q_{21}, and Q_{22} adjacent to the interpolation point P. According to the distance between the four points and the P point, the weight value is obtained. And then $f(Q_{11})$, $f(Q_{21})$, $f(Q_{12})$ and $f(Q_{22})$ are interpolated horizontally to obtain the gray values $f(K_1)$ and $f(K_2)$ of points K_1, K_2, respectively. Finally $f(K_1)$ and $f(K_2)$ are interpolated vertically to obtain the final gray level f(P) of point P.

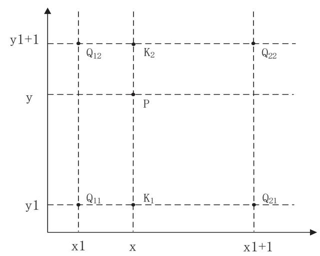


Fig. 2 Bilinear interpolation algorithm window

Therefore, the gray value of f(P) can be obtained from the bilinear interpolation window, as shown in Equation (1).

$$f(P) = f(Q_{11}) + [f(Q_{21}) - f(Q_{11})]\Delta x + [f(Q_{12}) - f(Q_{11})]\Delta y + \big[[f(Q_{22}) - f(Q_{12})] - [f(Q_{21}) - f(Q_{11})]\big]\Delta x \Delta y \quad (1)$$

Where, $\Delta x = x - x_1$, $\Delta y = y - y_1$.

Δx and Δy are the interpolation coefficient in the x and y directions, and related to the scaling factors K_x and K_y

of the original image and the scaled image. The image scaling is essentially the scaling of the original image rows and columns.

$$K_x = \frac{\text{sourcexres}}{\text{imagexres}}, K_y = \frac{\text{sourceyres}}{\text{imageyres}} \quad (2)$$

Where, sourcexres and sourceyres represent the number of the horizontal and vertical pixels of the original image, imagexres and imageyres represent the number of the horizontal and vertical pixels of the image scaling by the module, respectively.

It can be found that the scaling ratios in the x and y directions are different according to the scaling factors K_x, K_y. For the pixel whose coordinate is (x, y) on the scaled image, the scaling ratios are shown in Equation (3).

$$\Delta x = x \cdot K_x - [x \cdot K_x]$$
$$\Delta y = y \cdot K_y - [y \cdot K_y] \quad (3)$$

[ ] means rounding down. The coordinates of the pixel (x, y) on the scaled image correspond to the coordinates of the original image $(x \cdot K_x, y \cdot K_y)$, and the coordinates are rounded to $([x \cdot K_x], [y \cdot K_y])$. Then the coordinates of the four pixels around the pixel (upper left, upper right, lower left, and lower right) are $([x \cdot K_x]$-1, $[y \cdot K_y]$ +1), $([x \cdot K_x]$+1, $[y \cdot K_y]$+1), $([x \cdot K_x]$-1, $[y \cdot K_y]$-1), $([x \cdot K_x]$+1, $[y \cdot K_y]$-1), respectively. For example, the coordinates of the corresponding original image after calculation are (2.5, 4.5), then the nearest four pixel coordinates are (1, 3), (1, 5), (3, 3), (3, 5). The gray value is substituted into the formula (1) to find the gray value of the pixel with the coordinate (x, y) on the image after bilinear interpolation and scaling. The calculation process of the bilinear interpolation is shown in Fig.3.

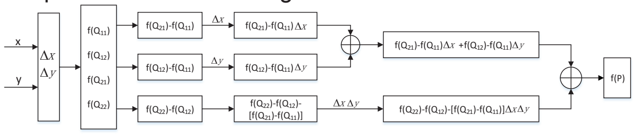


Fig.3 The calculation process of the bilinear interpolation

In the process of bilinear interpolation, it is necessary to interpolate data of two rows of the original image, so two RAMs are used to buffer two rows of data. And the depth of the RAM is the same as the number of columns of the original image. The data bit width is consistent with the input data width. Fig.4 shows the kernel structure of the bilinear interpolation algorithm module for display, and the frame rate of the played video can be reached.

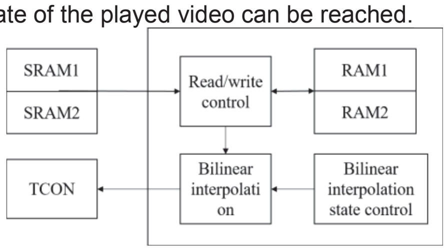


Fig.4 The kernel structure of the bilinear interpolation

2.3 The driving waveform

The EWD has a phenomenon of charge trapping. When a voltage is continuously applied to the pixel electrode, ions in the water move toward the insulator due to electrostatic force, some ions enter the insulator and trapped which make the oil can't be completely spread out. And the charge leakage will cause the EWD to turn off slowly,[5] as shown in Fig.5. Therefore, it is necessary to design a driving waveform that can precisely modulate the gradation and achieve high quality image display.

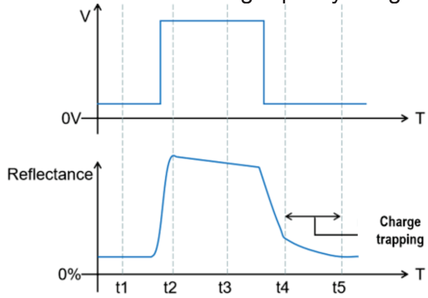


Fig.5 Charge-trapping phenomenon of the EWD

The gradation of EWD unit is determined by the magnitude and duration of the drive voltage applied to the unit. The traditional gray-scale dynamic asymmetric driving waveform[6] is shown in Fig.6. A total of 9 different gray levels can be generated for 4 sub-frames under the three driving voltages of 15V, -15V and 0V. The duration of each sub-frame is 17us, and the reset frame is used to return the oil to the original oil tile state[6].

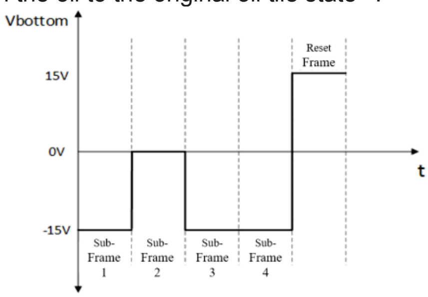


Fig.6 Dynamic asymmetrical driving waveform of gray level 9

The multi-gray dynamic symmetry driving waveform is shown in Fig.7. The driving waveform is divided into 3 parts which includes preset frame, display frame and reset frame. The preset frame is divided into 3 short sub-frames, and the driving voltage is gradually increased (the voltage of the common electrode is kept at +15V) to reduce the instantaneous electrostatic force result in stabilization of the oil movement. It can effectively inhibit oil splitting.[7] In the display frame, 5 sub-frames are used to display the image. The driving waveforms of the five sub-frames are symmetric, and the following 2.5 sub-frames repeat the waveforms of the preceding 2.5 sub-frames, so that the gray levels corresponding to the normal driving waveforms of the five sub-frames can still be achieved, but the four consecutive sub-frames can be greatly reduced. The probability of state greatly improves the phenomenon of charge trapping. The highest gray level corresponding to the driving waveform designed in this paper is not to make all sub-frames open at -15V, but is turned off in one of the five sub-frames, which further suppresses the phenomenon of charge trapping, making the image higher quality and clearer images. Finally, the multi-gray dynamic symmetric driving waveform proposed in this paper can achieve 15 gray levels. The reset frame is used to return the oil to the original state.

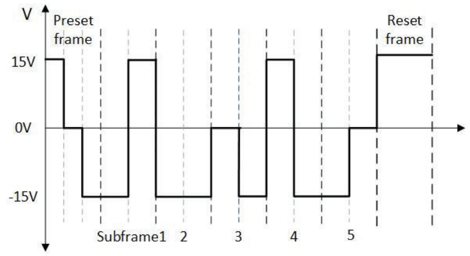


Fig.7 Dynamic symmetric driving waveform

3 RESULTS

The proposed driving waveform is implemented in the proposed driving system. The implemented driving scheme is shown in Fig.8. The smoothed video used is The Cars, a few frames of movie is captured in Fig.9.

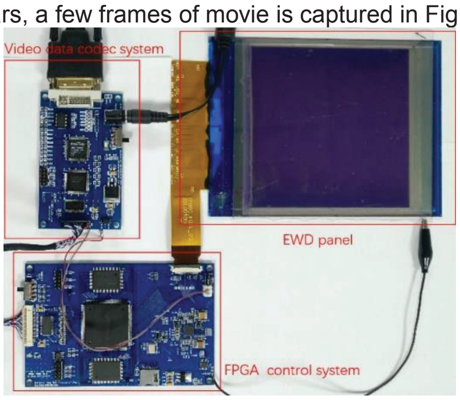


Fig. 8 The implemented EWD driving system

(a)

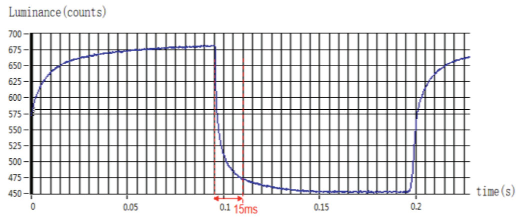
(b)

(c)

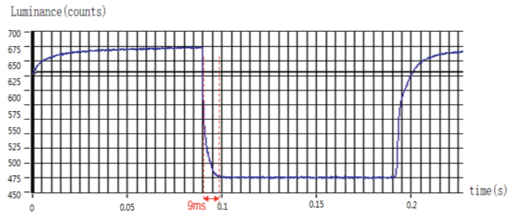
(d)

Fig. 9 A set of video frames driven by proposed driving scheme

The response curve measured by the colorimeter under conditional driving waveform and proposed driving waveform, as Fig.10 shows. The pixel closing time are about 15ms and 9ms, respectively. The closing time is reduced by about 40% under proposed driving waveform, thus the oil charge trapping phenomenon is improved.



(a)The response time under conditional driving waveform



(b)The response time under proposed driving waveform

Fig. 10 The response time between two kinds of driving waveforms

4 CONCLUSIONS

This paper proposes a DVI video image codec system for EWD plus FPGA timing control drive architecture, successfully achieving a frame rate of 30 frames per second for an EWD with a resolution of

1024×768. Dynamically play 15 grayscale videos in real time. The multi-gray dynamic symmetrical driving waveform proposed in this paper suppresses the oil splitting and charge trapping phenomenon while improving the gray level, which makes the video image display clearer and higher in quality.

ACKNOWLEDGMENTS

This work was financially supported by the National Key Research and Development Program of China (Grant No. 2016YFB0401503), Science and Technology Major Program of Guangdong Province, China (Grant No. 2016B090906001), Science and Technology Major Program of Fujian Province, China (Grant No.2014HZ0003-1), and Guangdong Provincial Key Laboratory of Optical Information Materials and Technology, China (Grant No.2017B030301007). Thanks to the South China Normal University for providing the monochrome EWD panel.

REFERENCES

[1] R. A. HAYES and B. J. FEENSTRA. "Video-speed electronic paper based on electrowetting," Nature ,Vol. 425, No. 6956, pp. 383-385 (2003).

[2] R. van DIJK, B. J. FEENSTRA, R. A. HAYES, I. G. J. CAMPS, R. G. H. BOOM, M. M. H. WAGEMANS, A. GIRALDO, B. V. D. HEIJDEN, R. LOS and H. FEIL. "68.3: Gray scales for video applications on electrowetting displays," Proc. SID, (2006).

[3] H. Y. JUNG, U. C. CHOI, S. H. PARK, H. S. HWANG, C. W. PARK, B. H. YOU, J. H. CHOI. "P‐48: Development of driver ic with novel driving method for the electrowetting display," Proc. SID (2012).

[4] X. M. ZHANG, P. F. BAI, R. A. HAYES, L. L. SHUI, M. L. JIN, B. TANG, G. F. GUO. "Novel driving methods for manipulating oil motion in electrofluidic display pixels,". Journal of Display Technology, Vol. 12, No.2, pp. 200-205 (2015).

[5] Y. C. CHEN, Y. H. CHIU, W. Y. LEE, C. C. LIANG. "56.3: A charge trapping suppression method for quick response electrowetting displays," Proc. SID (2010).

[6] Z. J. LUO, W. N. ZHANG, L. W. LIU, S. T. XIE, G. F. GUO. "Portable multi-gray scale video playing scheme for high-performance electrowetting displays," J. SID, Vol. 24, No. 6, pp. 345-354 (2016).

[7] C. C. LIANG, Y. C. CHEN, Y. H. CHIU, H. Y. CHEN, W. Y. CHENG, W. Y. LEE. "27.3: A decoupling driving scheme for low voltage stress in driving a large‐area high‐resolution electrowetting display," Proc. SID (2009).