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A novel driver for active matrix electrowetting displays

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ABSTRACT

Electrowetting display (EWD) is a reflective display technology in which fluidic pixels can response and switch quickly by electronic control, showing the capability for video-speed reflective display applications. In this paper, a new driver system is proposed and realized for video playing function of active matrix electrowetting display (AM-EWD). The hardware system is designed based on Field-Programmable-Gate-Array (FPGA) and the existing electrophoretic display (EPD) driving integrated chips (IC). A driving logic circuit and FPGA software is introduced for providing the EWD system with driving and timing control. And a set of specific driving waveforms, which is loaded to a lookup table of the FPGA in advance, is designed to display grayscale on EWDs. *4-level gray scale videos* have been successfully performed by applying the driving waveforms. To our knowledge, such work has not been reported before.

1. Introduction

Paper-like displays have become one of the important information visualization tools as represented by various EPD based e-readers from Amazon and Sony companies [1]. Currently, the response speed of EPD is still too slow to play video smoothly [2]. However, the reflective paper-like display still provides certain competitive advantages which liquid crystal displays (LCD) cannot do. The EWD based on electrowetting driven dual-liquid system was published by Hays in 2003 [3]. It displays information via reflective mode with quick response in <10 ms which is suitable for playing videos. In addition, EWD has the advantages of easy manufacture [4], high transmittance, bright color [5] and low-power consumption. These properties make EWD devices well-suited to portable devices, which are often used outdoors for showing video content. Near and mid-term product opportunities are logically expected in the areas of wearable multi-media, (smart) phone, portable gaming, pads and laptops.

Similar to the LCD technology, the EWD device requires active matrix backplanes for high resolution video playing [6], and the specific driving ICs are also necessary for EWD product applications. In order to show the gray scales, a timing controller (TCON) is needed to control the work time of gate and source ICs for writing a gray value to one pixel. Pulse width modulation (PWM), which is usually called driving waveform, can be implemented with fast scanning the thin-film transistor (TFT) array and provide different voltage states to a pixel electrode in different scanning frames with the help of TCON. However, a complete AM-EWD driving system has not been reported yet. Moreover, there is still no specific TCON for EWDs in the market up to now. Another important issue is that the driving voltage of EWDs is much higher than LCDs [7], therefore the driver IC of LCDs cannot be directly applied on the EWD devices.

In order to develop a complete EWD device, a specific driving system is essential. Firstly, a FPGA was used to realize the function of a TCON in the driving system and a set of driving waveforms was designed on the basis of display material properties to meet the display requirement of gray scales. Secondly, the driving voltage difference of the EPD source IC can reach 30 V [8], which is enough for the driving voltage requirement of EWDs device. Therefore, a new driver system, based on FPGA and EPD driving ICs, was proposed to provide hardware platform for video frame image display on EWDs. Hereby, the cost of the driving system can be reduced greatly without redesigning specific driving ICs. And then a FPGA which can form a custom IC was used as a TCON for coordinating driver ICs' action. Meanwhile, a series of driving waveforms were designed according to the pixel display performance for gray scale transformation and were downloaded into a configurable lookup table of the FPGA. Experimental results show that the driving system could play multi-gray video very well on EWDs.

2. Electrowetting display background

Information displays are typically made of tiny 'pixels' beyond the limit of visual resolution. These pixels are either emissive

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(e.g. cathode ray tube, plasma, organic light-emitting diode), transmissive (e.g. liquid crystal display, where the switch modulates light coming from the backlight), or reflective (E-ink and others, where the switch modulates ambient light). By modulating the emission or absorption characteristics of the optical switch, a display image with gray scales can be obtained. We have demonstrated that the electrowetting phenomenon can be used to make an efficient display pixel [3]. The principle of electrowetting displays is summarized in Fig. 1.

The optical 'stack' consists of solid components – reflective substrate, a transparent electrode, a thin layer of fluoropolymer insulator, the pixel walls and the liquids: dyed oil and conductive aqueous solution. The oil forms a thin film in the pixels confined by 'pixel walls'. In the absence of a voltage, the oil forms a thin film (typically microns thick as determined by the pixel wall height) that covers the entire pixel surface. Because the hydrophobic surface (i.e. the amorphous fluoropolymer) has a strong preference not to be in contact with water. When a voltage is applied between the water and the electrode, the surface of fluoropolymer becomes polarized or charged, which modified the hydrophobic layer to become water wettable (hydrophilic). Due to the low energy favorable status, the water layer will try to access the surface. The oil layer was then pushed aside during the accessing process. Typically, the smaller area occupied by the oil residue corresponds to higher applied voltage. During the on-state, the fluidic motion results from the balance between electrical and interface stress. For the off-state the restoring interface forces prevail. This curtain-like control of the oil, which contains optically absorbing dye, is the basis of a simple but highly efficient optical shutter.

One of the key properties of electrowetting fluidic elements is their switching speed. The switching speed of EWDs depends on the size of a pixel, the thickness of the oil, and other geometric parameters [9]. Compared to other chemical and physical phenomena e.g. EPD, electrowetting fluidic motion is very fast (cm/s) and essentially constant. As the fluid element becomes smaller the switching time therefore decreases correspondingly. For elements with a dimension of around a few 100 μm, such as display pixels, the switching time is therefore in a few milliseconds (ms). The typical switching data in 315 μm × 150 μm pixels is shown in Fig. 2. In this case, either the on-switch or the off-switch occurs in 7–8 ms. Switching speed at this range is more than sufficient to show video content on information displays. As smaller pixel size would be used (higher resolution) the switching time could be further reduced.

For a high resolution video display application, active matrix backplane is a required component in EWD system. Then, gate and source ICs are used to drive the active matrix backplane according to the driving waveform. In this system, a FPGA is used as a main controller to load the driving waveform for video processing, and control the timing of the system. The details of the driving system are shown in the next sections.

3. The hardware system design

A complete EWD driving system should include a high-performance hardware system to support the software system application. The hardware system can be realized by using a FPGA which is a semi custom circuit in the field of special integrated circuits as a main controller. It fills in the gap of custom circuit and overcomes the number fault of original programmable gate circuit. In addition, a series of peripheral circuits are designed to support the operation of the main IC. In the EWD, a source and a gate IC is bonded on the display screen for providing driving voltage in the format of active matrix driving [10].

3.1. FPGA

In the hardware system, a cyclone four generation FPGA is used as the main controller. It is low power consumption and rich in logic unit, and can support Nios2 embedded processor. The basic principles of the design is as follows: the video data is stored in the flash IC, SDRAM is responsible for running the Nios2 of the FPGA and caches the image data of the video, serial port can be used to renew the video data, Epcs is a memory for storing the FPGA program and Nios2 program, a wire is used to provide the common electrode with +15 V. The system structure diagram is shown in Fig. 3.

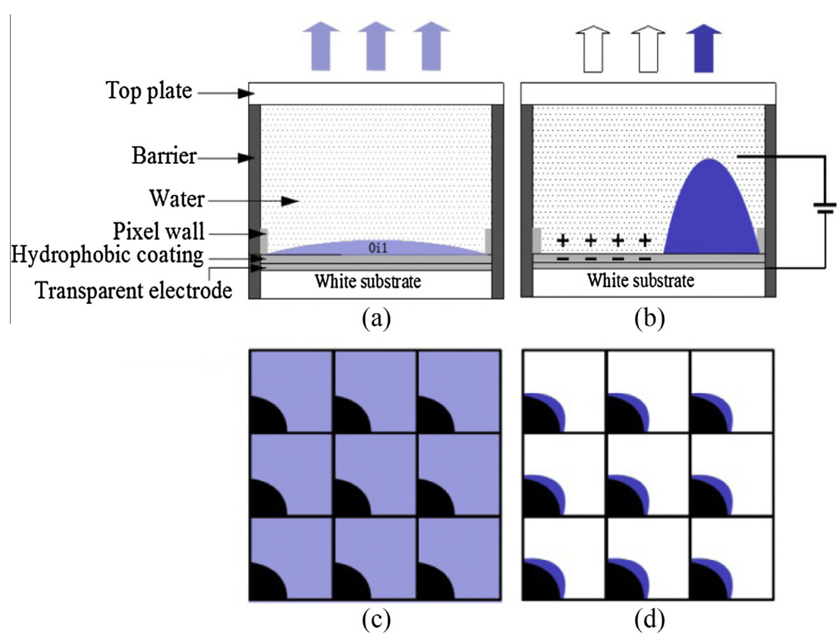

Fig. 1. An EWD pixel – principle and components. (a) Side view of electrowetting pixels when the oil is rolled out; (b) side view when the oil is pushed aside; (c) top view when the oil is rolled out; (d) top view when the oil is pushed aside (NB: oil thickness and droplet size not to scale).