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Improvement of video playback performance of electrophoretic displays by optimized waveforms with shortened refresh time ☆

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ABSTRACT

Electrophoretic display (EPD) has become one of the most important display technologies due to its bistability, low power consumption and outdoor readability. In this work, an image processing algorithm, which aims to enable video playback on EPD device without image distortion and grayscale loss by reducing the particle moving distance in EPD, is proposed and verified. The refresh time could be shortened by 22.2% with a video playback speed of more than 10 frames per second (fps) being achieved. This method could reduce the EPD switching time for quicker information displaying, and potentially extend the applications of EPD with video-like display property in the future.

1. Introduction

Electrophoretic display (EPD) is an important reflective display technology with low power consumption due to its bi-stable characteristics (preserving display content for long time without energy consumption) [1]. The ultra-low power consumption makes it distinguished from other display technologies from application perspective. In addition, light reflective property provides it with paper-like comfortable reading experience and outdoor readability. With these advantages, EPD has been widely applied for E-book readers. However, the low response speed makes it difficult to smoothly play video contents. Electrophoretic nanoparticles move in microcapsules as a function of driving voltages and the gray scale is determined by the driving waveforms. Studies on EPD driving waveforms have been conducted to improve display speed and applied to commercial E-Ink based EPD modules [2–5]. The core issue to be addressed is the video quality compensation to compressing driving time during the waveform design.

Similar to other active matrix (AM) displays, an active matrix backplane, a timing controller and a set of drivers are needed for building an electronic paper display device [6,7]. The active matrix backplane is used to provide voltage to the pixel electrodes. The duration of applied voltage can be controlled by opening or closing the gate of the thin film transistor (TFT) by a timing controller [8]. The source of the TFT directly supplies the pixel electrodes with various voltage sequences which are called driving waveforms. A typical driving waveform contains four stages: erasing the original image, resetting to the black state, clearing to the white state, and writing the new image [9]. For the same EPD materials, the switching speed and gray scale of the display are mainly determined by the driving waveforms.

Generally, a driving waveform with long time is needed to update a new image in EPDs [10]. Kao et al. [11] have studied the suspension viscosity, characterized the response latency of the device. They proposed a new driving waveform which could effectively reduce the driving time; however, the duration of the driving waveform was also too long to play videos. Wang et al. [12] employed four types of screen update modes according to the types of images. These modes could be applied to change the screen refresh modes; however, the fastest refresh duration was still 260 ms. Kao et al. [2,13] optimized the displaying window which had the maximum contrast ratio under different retention time conditions to shorten the updating duration; however, this method increased the burden of the processor and decreased the video quality.

In this work, a promotion scheme aiming for video displaying in EPDs is proposed to increase the number of displaying frames per second, namely the display speed. The wavelet packet

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transformation was used to analyze and process videos to reduce the distortion of the video content. A set of driving waveforms was applied to an EPD device to demonstrate the proposed mechanism. The driving waveform was downloaded to a real EPD waveform look-up table, and the processed video content was also downloaded to the controller memory to verify the validity of the promotion scheme.

2. Performance analysis of EPD particles and driving waveforms

Electrophoretic nanoparticles performance in EPD capsules should be analyzed and understood in order to drive them more efficiently. And then, the corresponding driving waveforms could be designed to improve displaying performance.

2.1. Particle performance in EPDs

EPD technology was proposed and studied in the early 1970s [14]. With the introduction of microcapsules, EPD technology was successfully brought into real applications. Firstly, particles were able to be isolated in a finite volume microcapsule. Secondly, distinct gray levels were achieved by controlling the voltage applied to pixelated electrodes. In general, the electrophoretic materials include electrophoretic particles, insulating oil, charge control agents and density balance agents. The schematic structure of an EPD microcapsule is shown in Fig. 1. The black and white particles are positively and negatively charged, respectively. Therefore, black and white colors are displayed when negative and positive electrical fields are applied to the microcapsules, as shown in Fig. 1(a). Gray scales are realized by mixing black and white particles at different ratios. Fig. 1(b) demonstrates a microscopic image in a EPD device with a voltage of −15 V and +15 V being applied to the left (white) and right (black) sections.

Charge control agent is used to prevent particle accumulation and increase electrophoretic movement. The equation for calculating a particle moving speed in a laminar flow driven by electrophoresis is described as [15]:

$$\mu = \frac{v}{\mathrm{E}} = \frac{\varepsilon\zeta}{6\pi\eta} = \frac{q}{12\pi r\eta}, \tag{1}$$

where μ is the electrophoretic mobility, v is the particle velocity, E is the electric field, ε is the dielectric constant of the internal fluidic, ζ is the zeta-potential, η is the internal fluid viscosity, q is the charge per particle, and r is the particle radius.

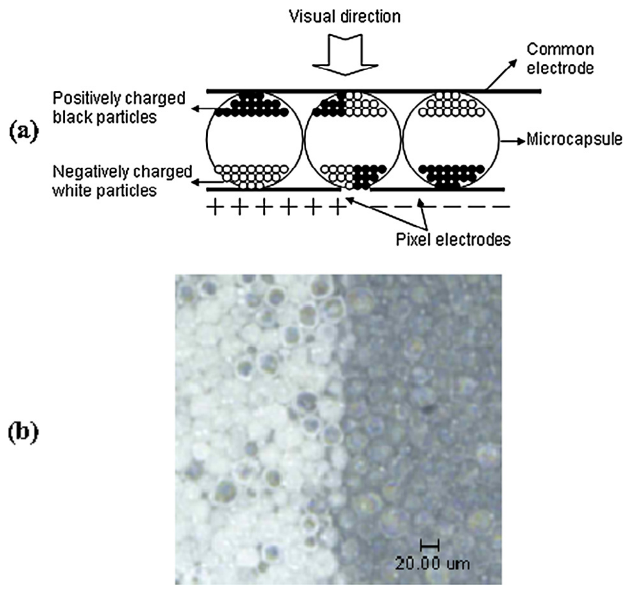

Fig. 1. (a) Schematic drawing of the working principle of the microcapsule-based EPD. (b) Microscopic image of the microcapsules showing white and black colors in an EPD device.

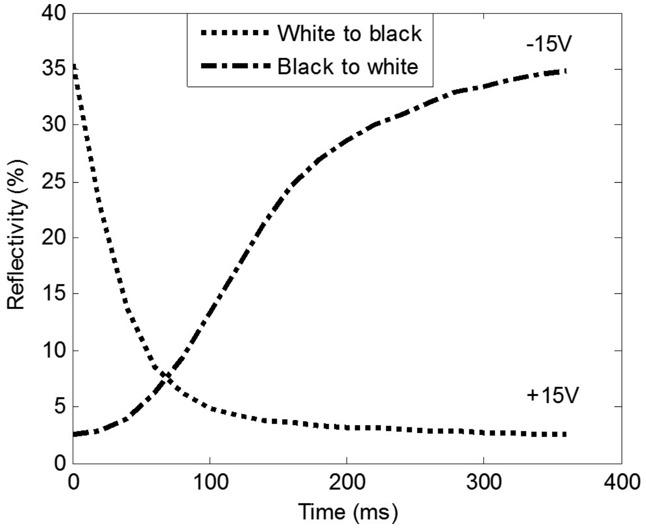

Fig. 2. Relationship between reflectivity and duration of applied voltage.

The relationship between reflectivity and the duration of voltage is shown in Fig. 2. It is obvious that it takes longer time to change from black to white than from white to black, and the switching time between white and black state is typically about 200 ms [9].

2.2. Driving waveforms

Generally, a driving waveform should effectively erase the previous image and rapidly write the new image. The rule of direct current (DC) balance must be obeyed at the same time. The residual DC may cause damage to the display if it is unbalanced. Conventionally, four stages are needed to build a driving waveform: 1st stage - erasing the original image, 2nd stage - resetting to the black state, 3rd stage - clearing to the white state, and 4th stage - writing the new image. The 2nd and 3rd stages are normally square waves with the duty cycles of 50%. Hence, these stages cannot lead to residual DC. The 1st and 4th stages could lead to DC imbalance and must cooperate with each other to form a DC balanced driving waveform. As shown in Fig. 3, the unit time is 20 ms when the frame rate of 50 fps is used. The waveform duration in each of the four stages must be an integer multiple of 20 ms, and the DC balance could be reached if $t_e = t_w$ is established [9]. The voltage state in each slot could be set to −15 V, 0 V, or 15 V.

In Fig. 3, the first three stages could reduce the occurrence of ghost images and activate two types of particles. In the refreshing

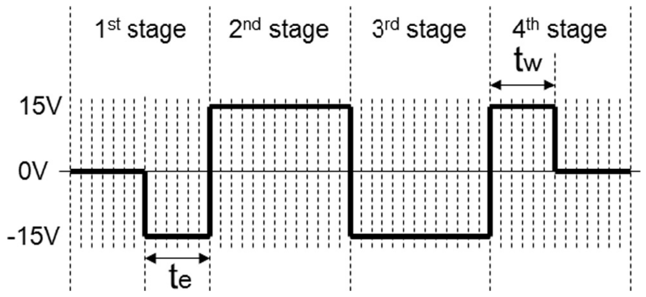

Fig. 3. An example of the conventional driving waveform.