Response Time Compensation of LCD with Integrated Thermal Sensor

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Abstract

This paper presents a thermally adaptive driving (TAD) technology for response time compensation of LCD with integrated sensor. The TAD is comprised of analog sensor signal conditioning and a digital feedback algorithm. Utilizing with a digital feedback system, TAD reduces response time of nearly 50% over the temperature range 0 ℃ - 60 ℃.

1. Introduction

Recent commercial LCD-TVs and monitors have become larger and brighter than traditional displays. This trend enables new opportunities not only for indoor but also for outdoor display applications. However, optical characteristics of TFT LCDs are significantly dependent on the panel temperature, hence, temperature characteristics of LCDs are still an issue [1]. For wide usage in thermally harsh environments, LCDs should use a robust temperature compensation system for high reliability and to maintain performance.

To compensate for temperature dependencies, a thermal sensor with feedback control could serve as a useful solution. However, it is complicated to accurately detect temperature of the liquid crystal (LC) layer, because conventional sensors can not be placed at the center of the panel without blocking pixels. In our previous work, we developed a new technology to accurately measure the internal LC temperature using a gate metal resistor sensor integrated onto the LCD panel [2]. We have now developed a system for use with that sensor. This paper presents thermally adaptive driving (TAD) technology for response time compensation of LCDs with the integrated sensor.

2. LC temperature dependency

We normally recommend the use of 1.0 (single) line spacing. However, when typing complicated mathematical text it is important to increase the space between text lines in order to prevent sub- and super-script fonts overlapping one another and making your printed matter illegible.

The threshold voltage (V_{th}) of optical transmittance can be expressed in terms of an elastic constant (k_{eff}) and the permittivity difference of LC molecules (△ε) as shown in equation (1).

$$V_{th} = \pi \sqrt{\frac{k_{eff}}{\varepsilon_0 \Delta\varepsilon}} \qquad (1)$$

According to the Ericksen-Leslie theory, LC material has five independent viscosity coefficients. Among the coefficients, Miesowicz's viscosity (r_1) is considered to be the dominant factor for rotational viscosity of liquid crystals [3]. The electro-mechanical LC equivalent model is shown in Fig. 1.

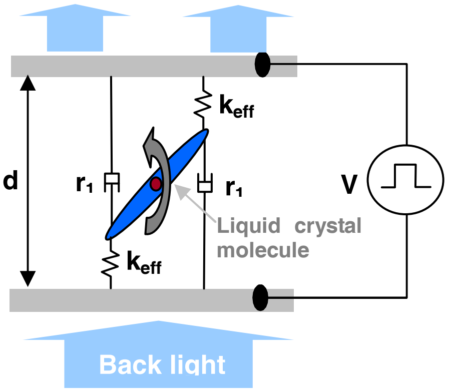

Fig. 1. Electro-mechanical equivalent model of liquid crystal

Turn-on and turn-off times can be described as a function of r1 and V as shown in equation (2) and (3). The turn-on time (T_{on}) is proportional to r1 and inversely proportional to pixel voltage (V). The turn-off time (T_{off}) is also proportional to r_1 and is expressed as equation (3).

$$T_{on} \propto \left(\frac{d}{\pi}\right)^2 \frac{r_1}{k_{eff}} \left(\frac{1}{v/v_{th}-1}\right) \qquad (2)$$

$$T_{\mathrm{off}} \propto \left(\frac{d}{\pi}\right)^2 \frac{r_1}{k_{eff}} \qquad (3)$$

Response times T_{on} and T_{off} are graphically described in Fig. 2. To reduce response time, an overdriving voltage (V_{DCC}) is applied to the pixel. This overdriving technique is widely used to reduce response times in commercial LCD-TVs.

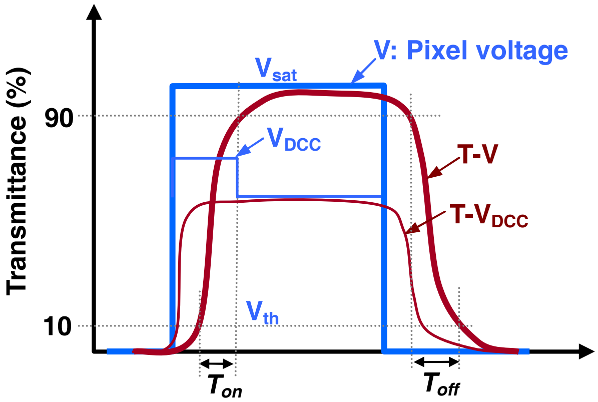

Fig. 2. Transmittance profile of liquid crystal at the applied step voltage input

Experimentally measured rotational viscosity of VA mode LC is shown as a function of temperature in Fig. 3. This viscosity increases exponentially in the range of 0-25℃. The LC's rotational viscosity at 0℃ is nearly 300% of its viscosity at room temperature. This temperature dependent viscosity strongly affects motion blurring performance of the panel.

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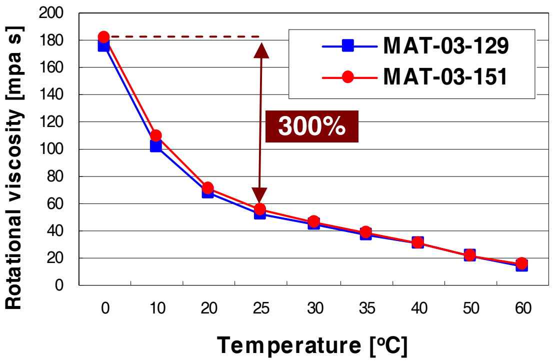


Fig. 3. Temperature dependence of LC rotational viscosity

3. TAD system architecture

The TAD system is composed of a temperature sensing section and a compensation algorithm embedded controller part as shown in Fig. 4. Metal film-type thermal sensors were integrated into the liquid crystal layer without any additional fabrication process steps. The sensors provided accurate panel temperature at the bottom, middle (2), and top positions of the LCD. As shown in Fig. 5, the temperature readout circuit consists of an external full-bridge circuit and a differential amplifier to minimize analog noise level. The analog sensor signal is converted to a digital signal by an 8-bit analog to digital converter (ADC) and then connected to a Xilinx FPGA system.

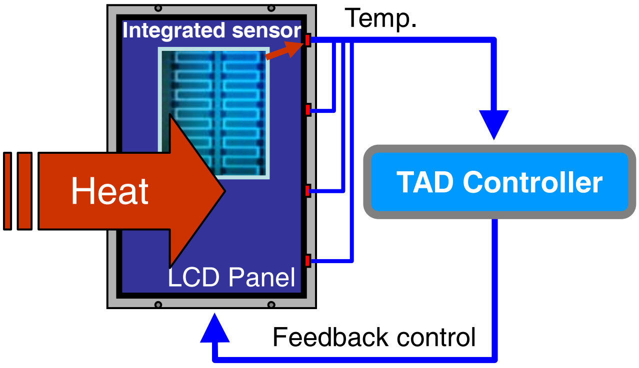


Fig 4. TAD integrated thermal sensor system architecture

As a kind of over driving technique to reduce response time and motion blurring, dynamic capacitance compensation (DCC) is widely used in commercial LCD-TVs [4].

The DCC algorithm compares previous and current frame gray levels and applies an overdrive voltage (VDCC) according to the gray level difference. A look-up table (LUT) in EEPROM contains the appropriate overdrive values. Conventionally, LUT values are based on rotational viscosity evaluated only at room temperature.

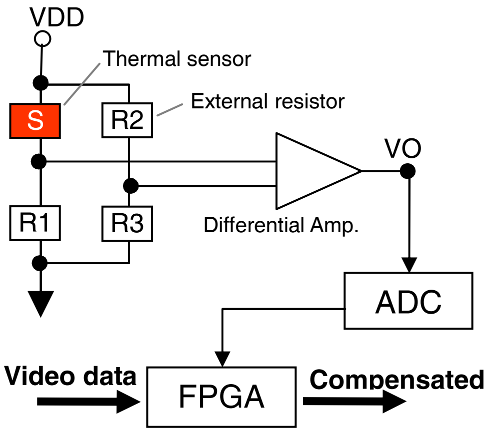


Fig 5. TAD system panel temperature sensor and readout circuits

The TAD algorithm embedded on the FPGA in Fig. 6 controls the acquisition time of sensing data and detects any sensor failure (open or short) to make a more robust system. The system has 8 sets of DCC tables corresponding to 8 ranges from 0℃ to 60℃ in order to compensate response times according to measured temperature. The overdrive values are proportional to the rotational viscosities of the LC material at the corresponding range. The TAD algorithm selects the appropriate LUT values according to the measured LCD panel temperature, thereby preserving response times at all temperatures.

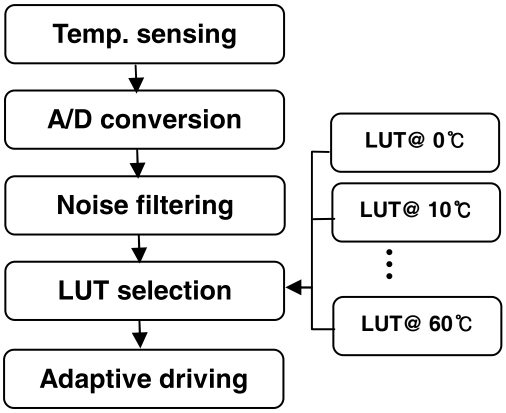


Fig 6. Flow chart of TAD for response time compensation

4. Experimental results

Our experimental setup for evaluation of the TAD consisted of a photometer (BM-7) and a PC based acquisition system as shown in Fig. 7. The automatic response time measurement software generated gray to gray level test patterns on the LCD and gathered response time data from the acquisition board. Profiles of gray to gray response times are shown in Fig. 8 using three dimensional graphs. At the 0℃ - 40℃ temperature range, gray to gray response times using the TAD system was reduced by amounts ranging from 10% to 80% compared to no feedback.

As shown in Figs. 9 and 10, the turn-on and turn-off response time were significantly reduced by the TAD system utilizing sensor feedback at 10℃, by 57% and 49% respectively. Average turn-on and turn-off time was reduced by 53% with the TAD system as shown in Fig. 11.

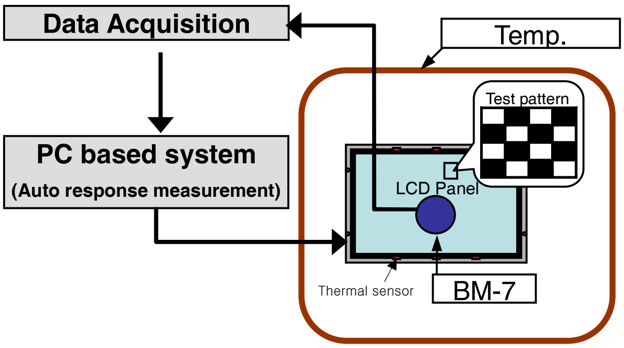
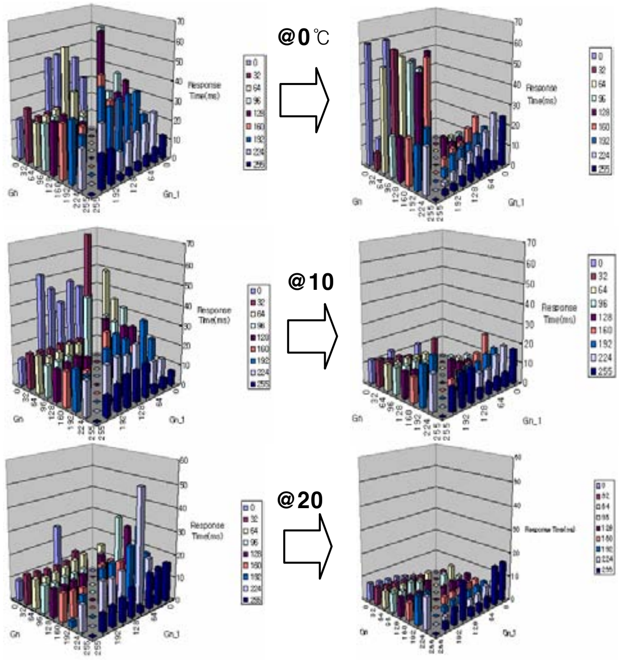


Fig 7. Test system for measurement on thermally dependent response time of LCD



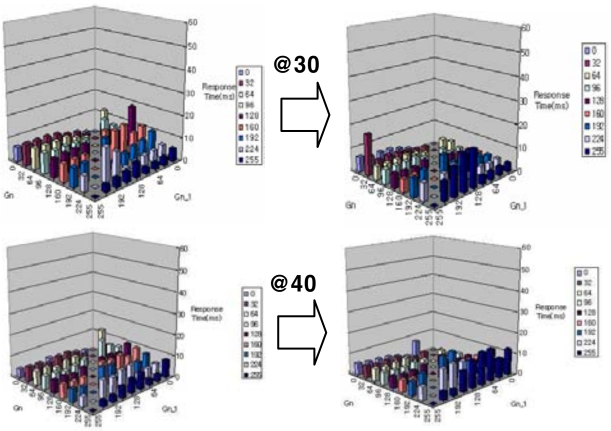


Fig. 8. Comparison of gray-to-gray response times without and with the TAD system

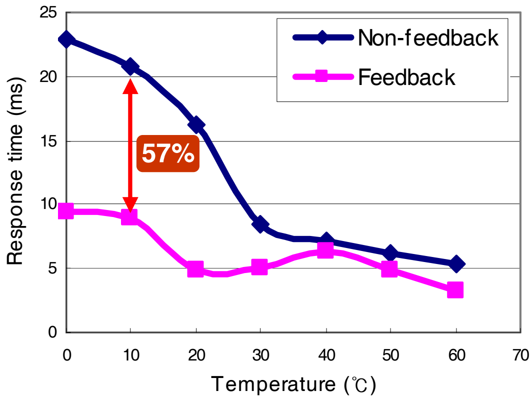


Fig. 9. Experimental results of averaged turn-on (T_{on}) response time with and without TAD system

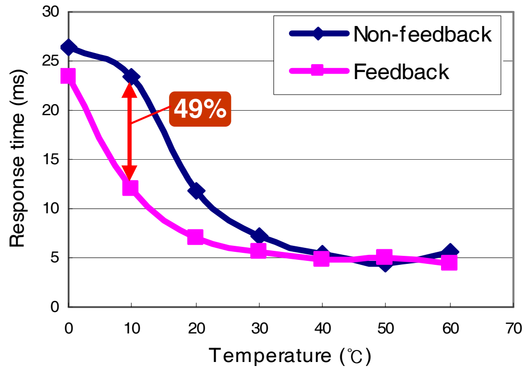


Fig. 10. Experimental results of averaged turn-off (T_{off}) response time with and without TAD system

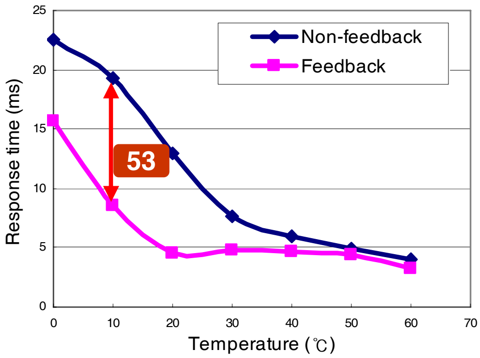


Fig. 11. Experimental results of overall rising and falling response times with and without TAD system

5. Impact

We have fabricated a TAD system with an integrated thermal sensor and temperature compensation algorithm. The TAD system includes an analog sensor signal conditioning circuit and a digital feedback algorithm implemented in an FPGA. The integrated thermal sensor provides accurate temperature measurement of the LC layer. The TAD controller has an 8-step LUT, and adaptively changes response time compensation according to measured panel temperature. Using the digital feedback algorithm, this system provided response time reduction of nearly 50% over the temperature range 0℃ to 60℃.

6. References

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