LCD response time estimation

Pierre Adam, Pascal Bertolino, Jean-Marc Chassery, Fritz Lebowsky

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*Pierre Adam**, *Pascal Bertolino, Jean-Marc Chassery*

Laboratoire des Images et des Signaux de Grenoble
961, rue de la Houille Blanche
Domaine Universitaire - BP 46
38042 St Martin d'Heres Cedex - France

Fritz Lebowsky

Home Video Division
STMicroelectronics
12, rue Jules Horowitz - BP 217
F-38019 Grenoble Cedex - France

ABSTRACT

Techniques to reduce LCD motion blur are extensively used in industry and they depend on an inherent LCD parameter: response time. However, normative response time is not a sufficient reference to improve LCD performance. Rather, all the gray-to-gray response times quantities are required to obtain a good improvement quality. Consequently, we propose a novel LCD model to simulate as well as compute gray-to-gray transitions (response time and behavior) from a reduced measurement set.

1. INTRODUCTION

Recently, active matrix liquid crystal display acceptance has considerably increased for PC monitors and TVs. TFT-LCDs carry the advantage of flatness, weight, low power consumption and high resolution but also, share an inherent weakness, motion blur due to a hold type driving method and response time of liquid crystal cells. This defect produces tailing phenomena and motion blur, easily detected as a visual artifact.

For many years, reducing the LCD response time has been an industry focus to improve display image quality. Many solutions were proposed such as black insertion [1], blinking backlight [2], double frame-rate [3], motion compensated inverse filtering [4] and the widely used technique introduced in 1992, called overdrive [5].

However, speeding-up the LC pixels response time with overdrive methods needs a Look-Up-Table (L.U.T.) which contains correction data. These values are obtained with measurements of original liquid crystal cell response time. Figure 1 shows an example of gray-to-gray response time for rising transitions, obtained from a 19-inch Twisted Nematic (TN) LCD monitor.

A basic process to correctly fill a L.U.T. takes an excessive time even if some promising efforts recently appeared [6].

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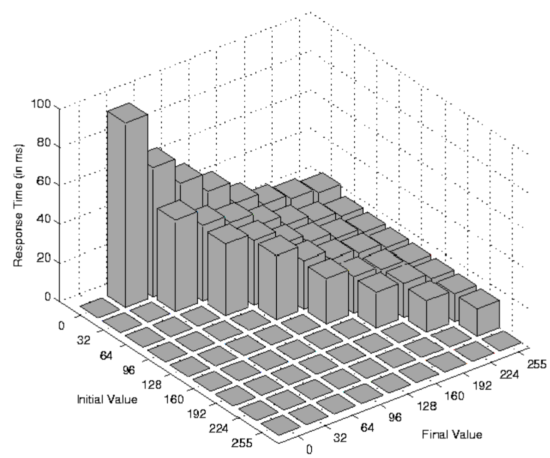

Fig. 1. Discrete gray-to-gray response time for rising transition

For instance, a 32×32 Look-up-Table needs at least 496 response time measurements for rising transitions to be correctly filled. However, this amount of measurements can be drastically reduced. Therefore, we introduce a new approach to radically simplify the gathering of response time data by modeling the behavior of LC cells transition and by estimating gray to gray response times.

In this paper, we first define a mathematical set of functions used for the model. Then, we split our model in two parts: transitions with zero initial gray level and non-zero initial gray level. We also evaluate its performance with data acquired from a TN LCD monitor.

2. RESPONSE TIME DEFINITION

Let $\mathbb{L}_n = \{L_i | 0 \leqslant i < n, L_i = i\}$ be a closed set containing n integers representing initial and final gray level values of transitions. For example, with 8 bit coded colour components, $\mathbb{L}_{256} = [0..255]$ and the total of gray level equals 256. Define $\mathbb{T}$ as a new closed set generated by $\mathbb{L}_n$ and representing gray level transitions from $\mathbb{L}_n$ to $\mathbb{L}_n$; $\mathbb{T}$ is a set of integer pairs:

$$\mathbb{T} = \{(x, y)|x \in \mathbb{L}_n, y \in \mathbb{L}_n, x \neq y\} \quad (1)$$

where x and y are respectively the initial and the final gray level of the transition. Then, the order of the elements is primordial and (x, y) is different from (y, x).

Define two subsets $^{\downarrow}\mathbb{T}$ and $^{\uparrow}\mathbb{T}$ from $\mathbb{T}$, one of falling transitions (from a gray level to an inferior one) and one of rising transitions (from a gray level to a superior one), by :

$$^{\downarrow}\mathbb{T} = \{(x, y)|(x, y) \in \mathbb{T}, x > y\} \quad (2)$$
$$^{\uparrow}\mathbb{T} = \{(x, y)|(x, y) \in \mathbb{T}, x < y\} \quad (3)$$

Concerning our present model, only rising transitions (elements of $^{\uparrow}\mathbb{T}$) will be estimated.

Split $^{\uparrow}\mathbb{T}$ into two subsets: $^{\uparrow}\mathbb{T}_X$ the subset of rising transitions with a fixed initial value equal to X and $^{\uparrow}\mathbb{T}^Y$, the subset of rising transitions with a fixed final value equal to Y. So, we have :

$$^{\uparrow}\mathbb{T}_X = \{(x, y)|(x, y) \in {}^{\uparrow}\mathbb{T}, x = X\} \quad (4)$$
$$^{\uparrow}\mathbb{T}^Y = \{(x, y)|(x, y) \in {}^{\uparrow}\mathbb{T}, y = Y\} \quad (5)$$

In particular, $^{\uparrow}\mathbb{T}_0$ represents the zero initial gray level transitions while $^{\uparrow}\mathbb{T}_*$ represents the non-zero initial gray level transitions.

Define L_i and L_f respectively as the values of an initial gray level and a final gray level. Finally, define $T_{L_i}^{L_f}$ as the transition from initial gray level L_i to final gray level L_f.

Let $\mathcal{C}(t)$ be a bounded and strictly-monotonic function from $[t_0; \infty]$ to $[L_i; L_f]$. Define t_{10} and t_{90} as the time instant when $\mathcal{C}(t)$ reaches 10% and 90% of the final value, i.e:

$$C(t_{10}) = L_i + 0.1 \cdot (L_f - L_i) \quad (6)$$
$$C(t_{90}) = L_i + 0.9 \cdot (L_f - L_i) \quad (7)$$

The response time of $\mathcal{C}(t)$, denoted τ, is then computed [7]:

$$\tau = t_{90} - t_{10} \quad (8)$$

Figure 2 depicts the relationship between the transition curve and the response time.

3. MODEL OF TRANSITION WITH ZERO INITIAL VALUE

In this section, we begin to construct our model with the subset of rising transitions of which initial gray level is zero, $^{\uparrow}\mathbb{T}_0$, by estimating the response time and the LC behavior.

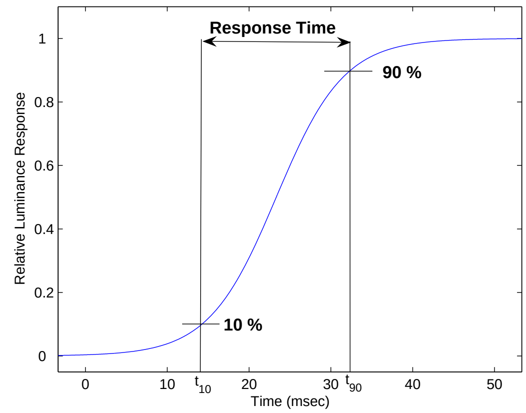

Fig. 2. Response time computation

3.1. Response Time

As shown in Figure 1, the response time of $^{\uparrow}\mathbb{T}_0$ is a decreasing function of the final gray level. To avoid taking too many measurements on a display panel, we estimate the behavior of the response time as a n^{th} order polynomial function of the final gray level, i.e,

$$\tau = \sum_{k=0}^{k=n} (a_k L_f^k) \quad (9)$$

where $(a_k)_{0 \leqslant k \leqslant n}$ are denoted as unknown constants to be found and τ and L_f respectively the response time and the value of the final gray level of the transition. A polynomial function was chosen because of its possibility to fit with any type of LCD (TN, IPS and VA). To parametrize $(a_k)_{0 \leqslant k \leqslant n}$, we create a system of polynomial functions which needs at least $n + 1$ different measurements (final gray level and associated response time); but the more the amount of measurements increases, the less the model includes systematic errors. Figure 3 shows an estimation of response time with a third order polynomial function parametrized with 7 measurements on a TN LCD monitor.

3.2. LC behavior

The next step is to model the transition as a temporal evolution of gray level. An example of a measured transition is illustrated in Figure 4. With a general approach to keep the two horizontal asymptotes and the general behavior of the curve, a hyperbolic tangent model is proposed. Physically, this modelization aims at representing the switching on of the LCD cell.

To correctly fit the model to the actual behavior of all LC transitions, our function needs three parameters: the response time (τ) which lets the transition's velocity evolve, the final gray level (L_f) for changing the final vertical asymptotic

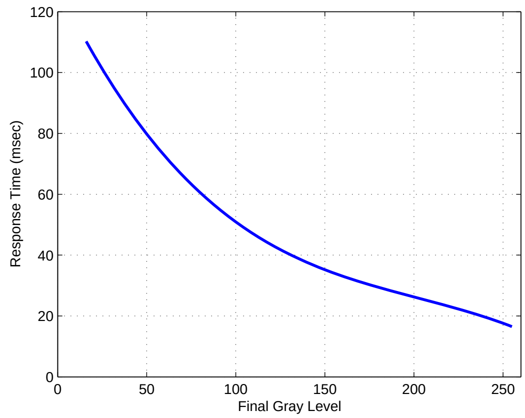

Fig. 3. Example of ${}^{\uparrow}\mathbb{T}_0$ response time polynomial function

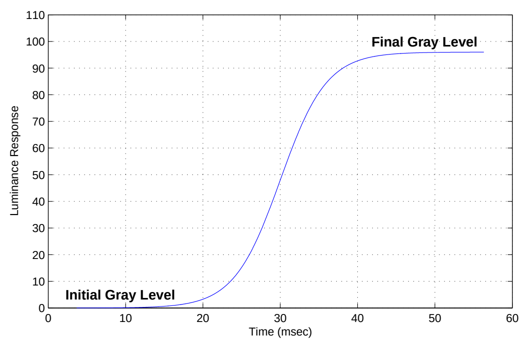

Fig. 4. Example of transition from 0 to 96.

value and a temporal shift (t_I) which centres the model in the correct temporal window.

Therefore, the LC's behavior can be described by the following equation:

$$f(t) = \left(\tanh \left(\frac{2 \cdot \tanh^{-1}(0.8) \cdot (t - t_I)}{\tau} \right) + 1 \right) \frac{L_f}{2} \tag{10}$$

We notice that this function is bounded between 0 and L_f and that the response time computation formula, presented in section 2, applied on the curve $f(t)$ allows to extract the simulated value τ.

4. MODEL EXTENSION TO OTHER TRANSITIONS

After modeling the transitions of ${}^{\uparrow}\mathbb{T}_0$ (section 3), we extend the model to ${}^{\uparrow}\mathbb{T}_*$. Figure 5 shows the superposition of actual measurements: one transition from ${}^{\uparrow}\mathbb{T}_0$ and three from ${}^{\uparrow}\mathbb{T}_*$. According to this relationship, we can deduce the LC behavior of any ${}^{\uparrow}\mathbb{T}_*^Y$, from the curve of ${}^{\uparrow}\mathbb{T}_0^Y$.

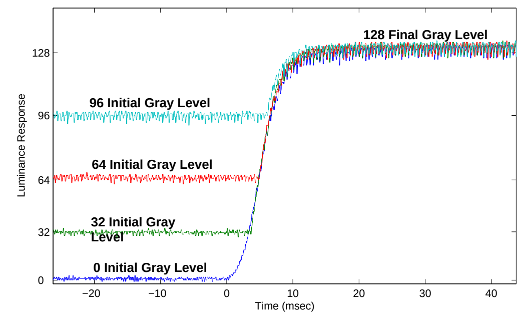

Fig. 5. Superposition of measured transitions

Consistent with Figure 5, the response time of ${}^{\uparrow}\mathbb{T}_*$ can be easily computed with equation (10). Equation (11) links the response time of ${}^{\uparrow}\mathbb{T}_0$ (τ) to the response time of ${}^{\uparrow}\mathbb{T}_*$ (τ') and can be written:

$$\tau' = \frac{\tau}{4.ln(3)}\, ln \left(1 + \frac{16}{1.8\, p + 0.2} \right) \tag{11}$$

with $p = \dfrac{L_i}{L_f}$, the ratio between the initial level and the final level of the transition.

When $L_i = 0$, we get the expected value $\tau' = \tau$. With respect to Eq. (1) and Eq. (3), L_i cannot be equal to L_f. Nevertheless, when L_i converges to L_f, p converges to 1 and the new response time τ' will converge towards $\dfrac{\tau}{2}$ instead of the commonly expected value 0. This result is due to our hyperbolic tangent model which never reaches its asymptote (the transition's final level). So, when p is close to 1, we have to consider the response time estimation as a theoretical value instaed of an actual result.

5. RESULTS

Tests were carried out on a 19-inch TN LCD monitor without any enhancement algorithm such as overdrive. Modelization of the response time from ${}^{\uparrow}\mathbb{T}_0$ transitions has been initialized with 7 measurements performed with a photodiode system.

Figure 6 compares the LC behavior on the L_0^{96} transition with our hyperbolic tangent model and a measured transition. The main parameter of the model (i.e the response time) is simulated by our polynomial function. Indeed, we obtain an absolute error, between our model and the measurement, which is equal to a maximum of 3 gray levels: the hyperbolic tangent function correctly fits with the actual transition. Moreover, the mean relative error is around 5% which is equal to the analog noise from the measurement system.

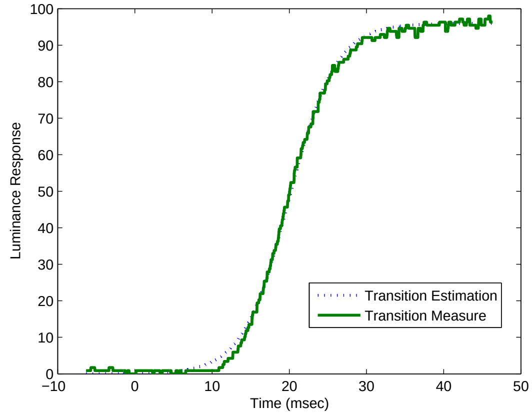

Fig. 6. Transition estimation and measurement

With the response time estimation presented in section 3.1, the LC behavior in section 3.2, and the response time computation of ${}^{\uparrow}\mathbb{T}_{*}$ in section 4, we can estimate the response time for the whole rising transition set. This theoretical response time estimation, shown in figure 7, represents 32640 values ($\frac{256\times256-256}{2}$) for a display panel with 8 bit per colour components.

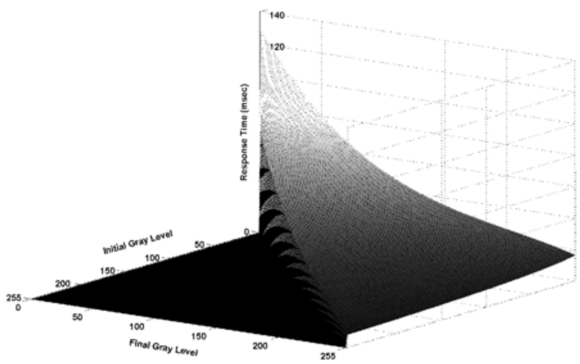

Fig. 7. Response time estimation

Our response time estimation is well-correlated with measurements in case $\dfrac{L_i}{L_f}$ is not close to 1 or in case $L_i = 0$. Actually, we obtain a mean response time estimation error around 7% in case $\dfrac{L_i}{L_f} < 0.8$ or $L_i = 0$, which represents more than 80% of possible rising transitions. The case $\dfrac{L_i}{L_f}$ close to 1 represents small rising transitions with a small response time. The obtained results differ slightly from measurements with a mean relative error close to 10%. In fact, a slight absolute error on response time estimation equals to a high relative errror on the final results. Nevertheless, these errors are very close to the analog noise from the measurement system and have only few consequences on the overdrive correction values.

The main purpose of our model is to speed up the generation of L.U.T. overdrive data. In fact, filling-up half of the overdrive 32×32 L.U.T. (corresponding to rising transition correction values) needs 496 response time measurements while with our model, only 7 measurements are required. Indeed, we save more than 95% of the time to take measurements.

6. CONCLUSION

In this paper, we proposed a general model to describe LCD response time behavior. This novel approach permits to determine the LCD response time through a simplified set of parameters and all the gray-to-gray response times can be easily obtained from a reduced measurement set. Finally, this model can help all the applications that need response time improvement (like overdrive) to reduce the computation time.

In the future, we will conduct a more detailed investigation on generalized response time estimation that will be applicable to the most LC Display types.

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