Characterizing Motion Performance with the Simulation Method

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Abstract

A simulation system is developed to calculate the apparent motion-induced image from a sequence of temporal luminance transitions, while using the properties of the human visual system. Based on the simulation method, both edge (moving block) and detail degradation (line spreading, grating, sinusoidal pattern), and also color aberration are discussed.

1. Introduction

Motion blur in LCDs is caused by the inconsistency between the sample-and-hold effect in LCDs and smooth pursuit eye tracking and temporal integration of light intensity at the human retina. The methods using 1) a pursuit camera [1]; 2) a high-speed camera [2]; or 3) a simulation model with step response, have been proposed to evaluate blur edge width (BEW) or MPRT [3-5]. However, next to the BEW, also contrast contributes to perceived sharpness [6]. Furthermore the BEW does not represent detail rendering and usefulness of the BEW for scanning backlight systems is questionable [7]. Therefore, some other parameters, such as line spreading [8] or DMTF [9] are proposed. In this paper the causes of motion blur and the principle to model motion artifacts on LCDs are discussed. Subsequently, a straightforward algorithm is proposed to calculate MPRT directly by the convolution of the measured temporal step responses with a moving window function of one-frame wide. Additionally, line spreading, grating, sinusoidal pattern and chromatic aberrations are simulated with frame-sequential temporal step response measurement. Finally the measurement system is presented together with the perceptual protocol, which was used to validate the simulation results

2. Modeling Motion Artifacts

Fig.1a illustrates a simple example where the eyes track one bright moving pixel on the dark background. The LCD is a hold-type display, viz., the object is stationary during one frame time and, at the next frame, jumps to another position related to the motion speed. Meanwhile, the eyes smoothly pursues the object with a constant speed v_r corresponding to the object speed v_p. The image position of the object on the retina is assumed stationary due to smooth-tracking of the eyes. The light intensity of each pixel (x_p) on the panel is represented by $Y(x_p,t)$. The corresponding light intensity received by the retina is indicated by $E(x_r,t)$. The perceived object $V(x_r)$ as indicated in Fig1.a, is blurred because of the LCD sample-and-hold effect, temporal luminance response, the smooth-pursuit eye tracking and temporal integration in the human visual system (Fig. 1b).

The simulation equation to calculate the perceived object is given by Eq.(1) [3, 5].

$$V(x) = \frac{1}{T_f}\int_{-\frac{x}{v}T_f}^{-\frac{x}{v}T_f+T_f} Y(m,t)dt \overset{discrete}{=} \frac{1}{T_f}\sum_{m=0}^{v-1}\int_{(m-x)T_f/v}^{(m+1-x)T_f/v} Y(m,t)dt \quad (1)$$

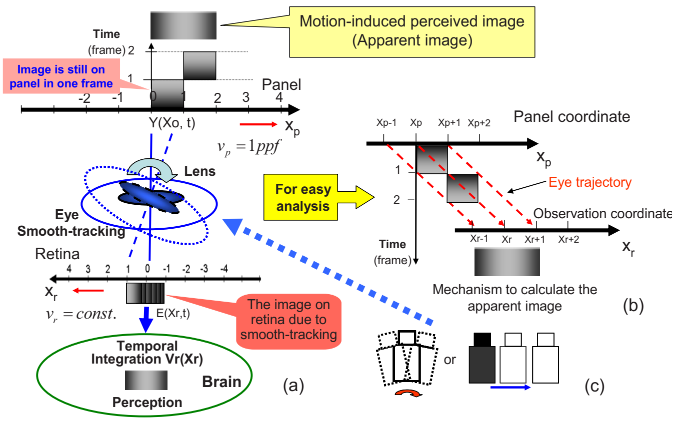

Fig. 1. The illustration of the sample-and-hold effect and the eye tracking a moving object on the LCD screen.

In Eq. (1), x is the position on the observation axis which is panel-projected retinal coordinate as shown in Fig.1b. Here T_f is the frame time, v is a constant motion speed in pixels/frame, and *Y(m, t)* is the temporal step response of pixel *m* (from 0 to *v*-1). *V(x)* is the perceived luminance at panel-projected retina position *x* after integration over one frame.

When an edge with a certain gray level is scrolling on a uniform background with another gray level, it is assumed that each pixel has the identical temporal step response behavior $Y_0(t)$. In that case, Eq.(1) can be transformed to:

$$V(x)=\frac{1}{T_f}\int_{-\frac{x}{v}T_f}^{-\frac{x}{v}T_f+T_f} Y_0(t)dt \qquad (2)$$

The profile of V(x) corresponds to the perceived luminance profile. Now τ is defined by:

$$\tau \equiv -\frac{x}{v}T_f \qquad (3)$$

With this transformation the luminance profile can be expressed as a function of time, since the motion speed is expressed in pixels/frame.

$$V(\tau)=\frac{1}{T_f}\int_{\tau}^{\tau+T_f} Y_0(t)dt \qquad (4)$$

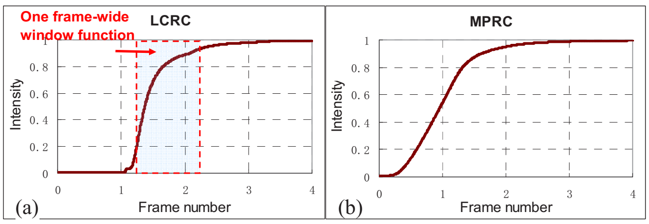

Fig. 2. (a) The LC response curve and a window function of one-frame wide (b) the MPRC.

From Eq.(4), *V(τ)* can be derived by the convolution of the measured temporal LCRC with a moving window function of one-frame wide [5] (see fig. 2a). *V(τ)* corresponds to Motion Picture Response Curve (MPRC), viz., normalized luminance profile of the perceived blurred image in temporal domain [fig 2(b)]. The assumed perceptual relevant parameters, such as EBET and MPRT can be directly obtained from *V(τ)*. The temporal coordinate can be transformed into spatial coordinate *via* $x \equiv -\tau v / T_f$, where sign "-" means "inverse", not negative.

3. Detail information degradation

The edge blur of a moving block does not reflect the detail information degradation. Thus alternative measures, such as the line spread or MTF method are required. The simulation method can also be used to calculate line spread and grating degradation as shown in the next section.

3.1. Line spreading and grating degradation

Eq.(1) can be used to calculate the motion-induced line spreading, but using one-frame impulse response instead of step response. Here w is the line width (in pixels), and v is the motion speed (in ppf). There are two cases 1) *v*≥*w* or 2) *v*<*w*. In the case that *v*≥*w* (as shown in Fig.3a.), Eq.(1) can be transformed as following:

$$V(x)=\frac{1}{T_f}\int_{-xT_f/v}^{(-x+w)T_f/v} Y_{impulse}(t)dt+\frac{1}{T_f}\int_{(-x+w)T_f/v}^{-xT_f/v+T_f} Y_B(t)dt \overset{\tau\equiv-\frac{x}{v}T_f}{\Rightarrow} \qquad (5)$$
$$\frac{1}{T_f}\int_{\tau}^{\tau+\frac{w}{v}T_f} Y_i(t)dt+\frac{1}{T_f}\int_{\tau+\frac{w}{v}T_f}^{\tau+T_f} Y_B(t)dt \overset{if Y_B(t)=0}{=} \frac{w}{v}\cdot\frac{1}{\frac{w}{v}T_f}\int_{\tau}^{\tau+\frac{w}{v}T_f} Y_i(t)dt$$

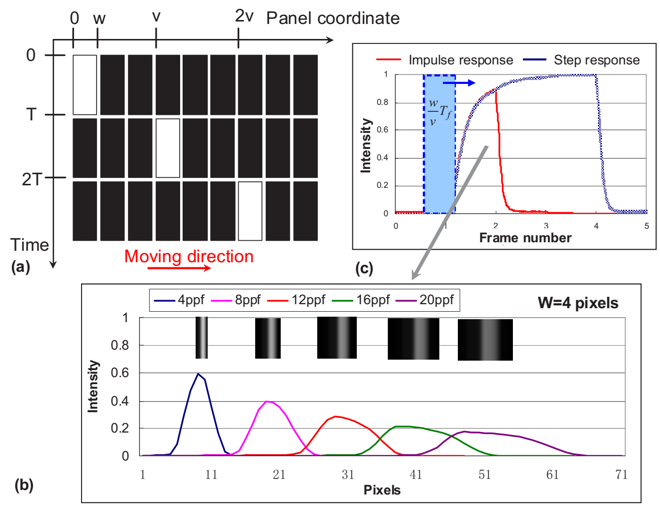

Fig. 3. Line spread function simulation from the temporal impulse response.

In Fig.3, $Y_i(t)$ is the LC impulse response and $Y_B(t)$ is the background luminance. If Y_B is assumed 0, the perceived line spread image can be simulated by the convolution of the measured impulse LCRC with a moving window function of *w/v* frame wide. Fig.3c shows the simulation line spread results for different motion speeds. In case *v*<*w*, the calculation method is the same as edge blur as described in section 2.

The grating degradation can be evaluated with a frame-sequential impulse response measurement. Consider, for example, a typical case with a grating period $p = 2 \times v$ as shown in Fig.4a. The retinal profile [V(x)] can be calculated via Eq.(4), but here $Y_0(t)$ is the frame-sequential impulse response curve as shown in Fig.4b.

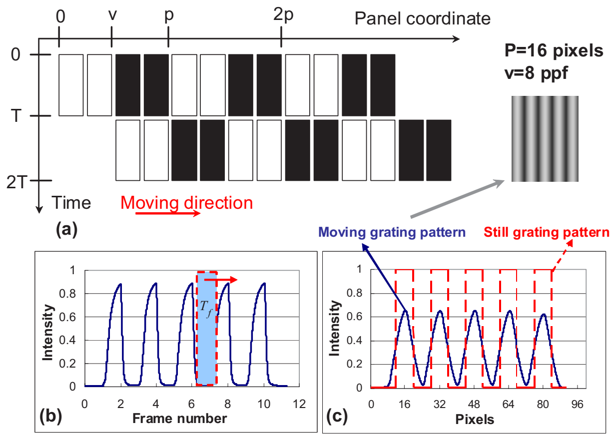

Fig. 4. Grating pattern simulation from the temporal impulse response.

The high level of the first impulse may be a bit different from subsequent impulses because it takes a few frames to get stable situation. Fig.4c presents the simulation grating patterns compared with the original still one. Fig.4c shows that the peak amplitude of moving grating decreases more than the lower level increases, because of the asymmetric behavior of slow rising and fast falling response. Other cases can be predicted by measuring proper frame-sequential step response curves, which is referred to the method explained in section 2 and 3.2.

3.2. The sinusoidal wave pattern

Next to methods, such as line spreading and grating degradation, a sinusoidal pattern is the most common pattern to obtain the dynamic MTF [9].

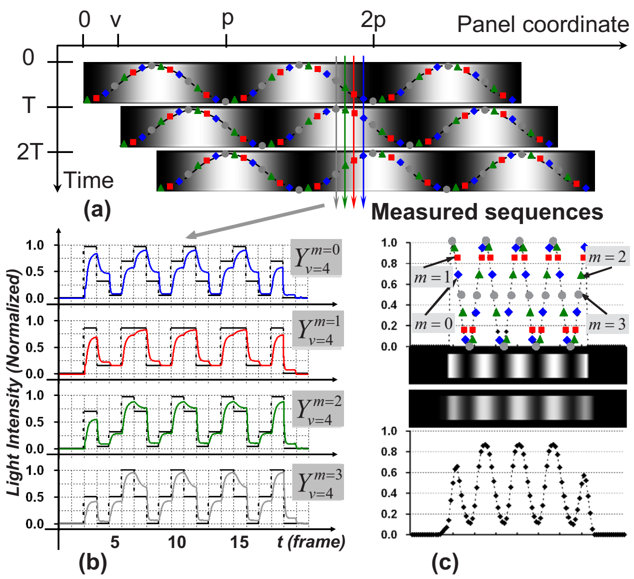

Fig. 5. Sketch map to simulate sinusoidal patterns.

A spatial sinusoidal pattern is periodic and can be discrete into pixel values, as shown in Fig.5a. The series of frame-sequential step response $Y_m(t)$ (m=0,1,2..v-1) is measured corresponding to initial and target gray level for each pixel, because sinusoidal periodic characteristics only need limited numbers (equal to v) of the frame-sequential step response curves to be measured. With Eq.(1) the perceived intensity is the total intensity, accumulated over each pixel that the eye moves across during a frame period. Fig.5 gives an example when v=4 ppf, where the perceived moving sinusoidal pattern can be calculated from 4 frame-sequential step transition curves with using Eq.(1). DMTF curves can be obtained by the variation of special frequency and motion speed.

4. Motion-induced Chromatic aberration

Most LCDs for TV-applications have red, green and blue color filters. Usually, the temporal luminance characteristics of the R, G and B sub-pixels are considered to be equal when black and white (B&W) patterns moving across the screen. In practice, however, the individual responses may deviate due to intermediate processing. Furthermore, in the case that a colored block is moving over a differently colored background, severe motion-induced chromatic aberration may occur, because of different liquid-crystal cell responses [10]. To investigate the perceived motion-induced chromatic aberration, the step response curves for R, G and B shall be measured individually. The already introduced algorithm to calculate motion blur is used to simulate the perceived chromatic aberration from these curves.

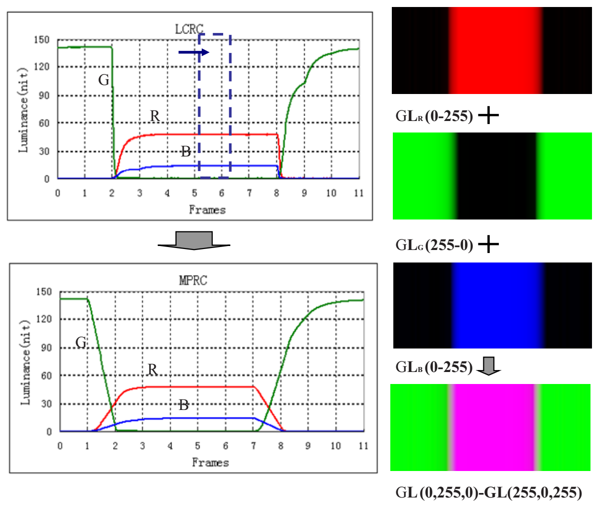

Fig. 6. Motion-induced chromatic aberration caused by differences between the temporal luminance transitions of R, G, and B.

The main difference is that in this case the temporal luminance characteristics of R, G and B have to be analyzed separately. Fig.6. illustrates the effect of different R, G, and B sub-pixel transitions when a colored block moves from left to right over a differently colored background. In this case the temporal luminance characteristics for R, G and B are different due to different start and end levels. The asymmetric rise and fall response characteristics of R, G and B channels also result in chromatic aberration at the leading and trailing edges.

5. Measurement system and perceptual validation

A measurement system (see Fig. 7) with a fast, eye-sensitivity compensated photo-diode has been built to accurately measure the temporal luminance transitions, needed as input for the simulation model [4, 9, 10].

A perceptual protocol was designed to validate the simulation results [4, 5]. A photograph of the set-up is shown in Fig. 8. The experimental results show a high correlation between the simulated apparent image and the actually moving one [4, 5, 10].

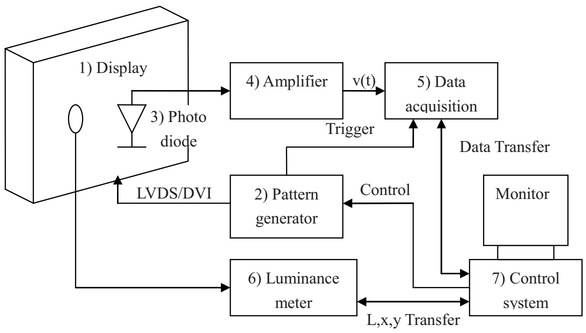

Fig. 7. The block diagram of the system to measure temporal luminance transitions

Fig. 8. Experimental set-up, the moving block (top) and the still simulated block (bottom) are shown on the same screen. The motion speed was adjusted by the participant to match the simulated still image.

6. Conclusions

Motion artifacts on LCDs can be characterized with smooth pursuit eye-tracking and temporal luminance integration. MPRT can be calculated directly by the convolution of the measured temporal step responses with a moving window function of one-frame wide. With appropriate step response, one-frame or frame-sequential impulse and frame-sequential step transition curve measurements, the perceived line spread, grating or sinusoidal pattern degradation and motion-induced chromatic aberration can also be characterized with our simulation system.

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8. References

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