10.1: Evaluation of Moving-Line Contrast Degradation without Motion

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Abstract

This paper introduces a method for evaluation of the contrast of a moving lattice (grille) pattern without imaging data acquisition and image analysis. We characterize the dynamic performance of the display under test in terms of the ***periodic impulse response*** followed by evaluation of the contrast of the corresponding test-pattern in motion. It thus becomes possible to simulate moving grille patterns with any pitch, arbitrary gray-levels and speed of translation by measuring the corresponding temporal luminance variations at a fixed location. This approach is attractive due to reduced instrumental efforts and the transparent evaluation based on suitable spatial contrast sensitivities.

1 Introduction

The display of moving images on flat-panel displays is affected by artefacts, especially when compared to CRT-based monitors and TV-sets. Measurement, evaluation and rating of motion artefacts is required for development and systematic optimization of suitable countermeasures and for objective specification of the performance of various flat-panel display technologies (i.e. LCD, PDP, etc) in product data-sheets.

1.1 Origins of motion blur

Visual targets with initially sharp edges traveling across an electronic display screen are often perceived as blurred by human observers. This is caused by the hold-type characteristics of the response of the display and by integration of the human visual system while smoothly following the movement of the target (i.e. *smooth pursuit eye-tracking*). Increased response times of LCDs, especially when switching between intermediate levels of gray, further deteriorate the visual quality of moving objects and thus contribute to motion blur, but they are not the actual cause.

The method of *eye-trace integration*, after its introduction by Kurita [1], has become the basis for evaluation of motion blur and has been discussed in a series of papers e.g. by Sekiya [2].

1.2 Measurement and evaluation of motion blur

Data for evaluation of motion-blur can be acquired in four ways with two kinds of test-patterns, with imaging detectors and spot-meters:

- moving patterns recorded with a tracking [3] or stationary [4] camera,
  - block-patterns, wide enough to allow settlement of the optical response to a stationary state and
  - line-or grille patterns (e.g. one pixel wide),
- stationary patterns (intensity vs. time measured at a fixed location on the display),
  - step-response: optical response settles to stationary state, [5],
  - impulse-response: activation for one frame period, [5]).

A direct reproduction of the tracking of a visual target by a human observer is attempted by the class of “pursuit camera systems” where the measurement field of the camera is put into motion by a moving mirror (e.g. galvanometer scanner, rotating polygon mirror) or by linear motion devices to track the target.

The contrast reduction of grille or sine-burst patterns [6] moving across a display screen and recorded with a tracking camera system (stationary high-speed or motorized camera) seems to be a convenient way for objective evaluation of the dynamical performance of electro-optical displays in detail (see e.g. [7]). The attractiveness of this method is given by the fact that the resolution of display devices can be characterized by the same characteristics (contrast modulation, see FPDM2 303-7 *Resolution from contrast modulation*) in the static and the dynamic case.

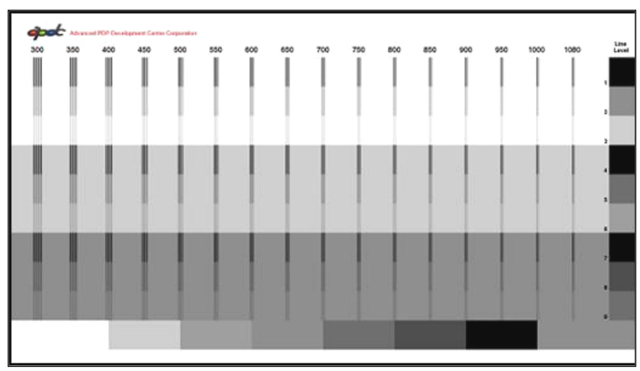


Figure 1: Example for a compound test-chart with a variety of grille-patterns; (grille pitch decreasing from left to right) three background and three foreground states for generation of 9 contrast levels (from [6]).

2 From moving patterns to temporal response

We first consider a single vertical line of width w [pixels], gray-levels G_1 and G_2 (foreground, background) and a measurement spot that is smaller than w (fig. 2). Movement of this line with a speed of Δ [pixels] per frame period (where $\Delta \geq w$) effects the pixels at a fixed location on the display to make a first transition $G_2 \rightarrow G_1$ for one frame at the arrival of the line and back again ($G_1 \rightarrow G_2$) when the line moves on during the next frame. This double transition at a fixed location is equivalent to the (single-shot) *impulse response* of the display shown in fig. 4. The impulse response of LCDs cannot be accurately constructed from parts of the step-response since the starting conditions for the second transition at the end of the first frame are different from those of the static case with the same luminance.

Line of width w, fixed measurement field M

Array of lines of width w (grille, grating)

Figure 2: Single line and periodic array of lines with gray-level of target (line) RGB1 on background RGB2

Smooth pursuit eye-tracking effects a *spreading* of the line the width of which is basically given by the advancement Δ of the line per frame period. The apparent total width of the line is $w_a = \Delta + w$ and, for a width of one pixel we obtain $w_a = \Delta + 1$.

When the transition of the optical response has a finite steepness (e.g. 0%-100% linear over one frame period), the (total) width of the line, w_a, becomes $w_a = (2 \cdot \Delta + 1)$ pixel.

Since the spreading of the line is very much determined by the advancement Δ, it does not provide significant information on the dynamical properties of the display.

The width of the spread of the line is specified here as the total width whereas *edge blurring* is usually measured as the time/distance between the 10% and 90% levels.

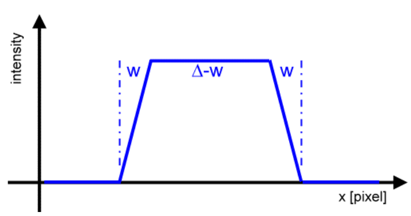


Figure 3: Spread of the perceived image of a vertical line of width w and advancement Δ [pixels] per frame period for an ideal hold-type display.

Due to the asymmetry of LCD switching (field-induced transition or relaxation) a dark line on a bright background has a different contrast than a bright line of a dark background [8]. This asymmetry is obvious in fig. 4 where the transition from light to dark (blue curve, decreasing voltage) settles completely within one frame period (16.7 ms) while the transition from dark to light (blue curve, relaxation of a normally-white TN-LCD) does not.

We are now considering the case of a multitude of vertical lines (grille, grating) with constant spacing, advancing on the display from left to right and we choose the case of w=1 and Δ=1. The temporal luminance response at a constant location within a line (fig. 2, right) periodically assumes one of two luminance levels each frame, L_1^* or L_2^* (*periodic impulse response*, see fig. 6B) which are different from both the static values L_1, L_2 and from the single-shot extremal values, $L_1'$and L_2'. With increasing width of the line, w, the response can settle after the first transition and the luminance vs. time curve gradually approaches the step response.

A measure for the ability to display moving images (i.e. for the degree of *motion blur*) can be obtained from the impulse response via Fourier transformation [5, 9], but this procedure does not readily provide the contrast of the moving target with respect to the background and thus no direct clue about its visibility.

The contrast of a moving line can be calculated from the luminance vs. time curve as illustrated in fig. 5. The luminance of the two optical states are integrated over one frame period (red and yellow area) and with the integrals I_1 and I_2 the contrast is:

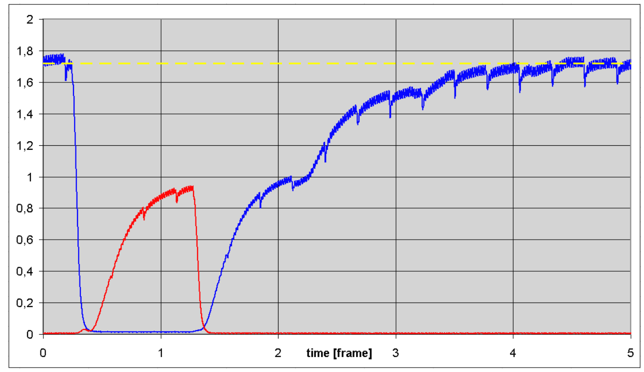


Figure 4: *Single-shot impulse-responses* between RGB=0 and RGB=255 for a normally-white TN-LCD exhibiting pronounced asymmetry. The target-luminance is reached only with the (overdriven) field-induced transition of the LCD (blue curve).

$$C_{dyn} = \frac{L_{min} + \int_{frame1} L(t) \cdot (L_{max} - L_{min})}{L_{min} + \int_{frame2} L(t) \cdot (L_{max} - L_{min})} \quad (1)$$

with $I_i = \int_{frame\,i} L(t)$ = normalized integral

$$C_{dyn} = \frac{(L_{min} + I_1 \cdot (L_{max} - L_{min}))}{(L_{min} + I_2 \cdot (L_{max} - L_{min}))} \quad (1a)$$

and $C_{stat} = L_{max} / L_{min}$

For the ideal hold-type display I_1=1 and I_2=0 and $C_{dyn} = C_{stat}$.

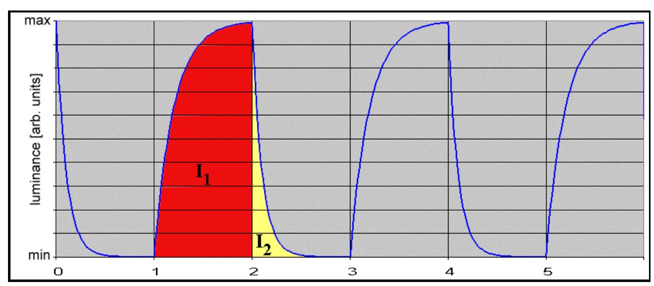
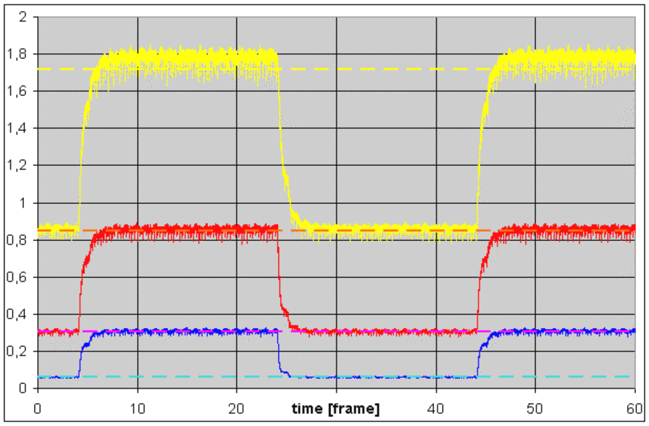


Figure 5: Dynamical contrast between adjacent frames is given by the individual frame-integrated luminance values I_i here illustrated for $\tau_R = 2 \cdot \tau_F = 0.2\ T_{Frame}$. in red and yellow.

The variation of the dynamic contrast, C_{dyn} with the time constant of the transitions as calculated for illustration is listed in table 1.

$\cdot\tau_F$	0.001	0.1	0.2
τ_R	0.002	0.2	0.4
C_{dyn}	299.998	8.54	3.61
C_{stat}	300	300	300

Table 1: Dynamic contrast reduction calculated for exponential time dependence with different time constants, t_R and t_F $[T_{Frame}]$ for rising and falling edge, respectively. L_{max}=300, L_{min}=1



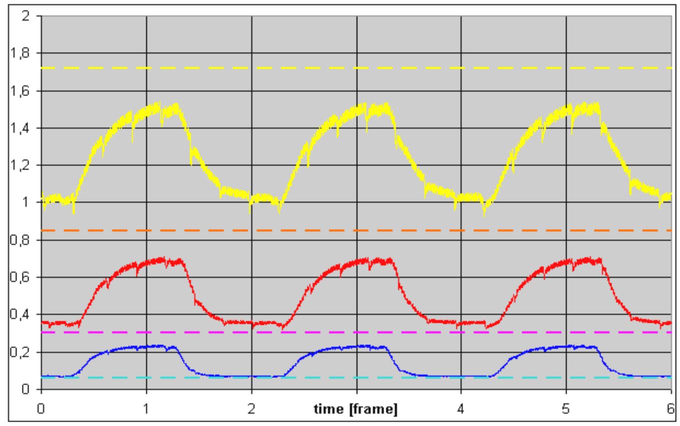


Figure 6A: Transitions with widths of 20 frame periods (1 cycle per 40 frame periods) settling to a constant plateau-value and corresponding static luminance values (dashed horizontal lines).

Figure 6B: Transitions with widths of 1 frame period (*periodic impulse response*) and settled static luminance values (dashed horizontal lines) illustrating the effect of contrast reduction.

Transitions between input levels of 0%, 25%, 50%, 75% and 100% measured with the OTR-3 [10] @ 60Hz frame frequency [14]. The ripple on the curves are periodic intensity fluctuation caused by the PWM of the backlight dimming circuit of the LCD-monitor.

The contrast corresponding to the 75% and 100% states (yellow curve in fig.6B) is reduced from 2.02 in the static state (fig. 6A) to C_{dyn} = 1.24 in the periodic case (fig. 6B) and the corresponding contrast modulation from C_M = 0,339 to C_M = 0.105. Contrast modulation is obtained by evaluation of the integrals according to eqn. 1 over one frame period of the *periodic impulse response*.

3 Estimation of visibility

Depending on the impulse response of the display under test, details of the moving grille can be resolved in the image taken with a tracking camera (i.e. the contrast modulation is above the visibility threshold, fig. 6 left) or the contrast is so low that only a blurred region without noticeable details can be observed (Fig. 9 right).

From the measured contrast modulation the visibility of the grille pattern basically can be estimated on the basis of the work of Peter Barten [11] carried out with patterns at rest. It should be taken into account that the visibility of moving patterns is different from that of the same patters at rest [12, 13].

4 MTF and contrast

The relation of impulse response and blurred edge width and the significance of the modulation transfer function MTF obtained from the (single shot) *impulse response* for the motion portrayal capabilities of LCDs has been derived and described in detail by Klompenhouwer [5, 9]. As can bee seen in fig. 8, even though the MTFs of yellow and red pulse are very much alike up to f_n ~0.8, the dynamical contrast (modulation) between the first and second frame is 0.427 (red) and 0.362 (yellow) respectively. Even when the MTFs are not normalized and the DC component of the Fourier transformation is taken into account, this does not provide the required information on the dynamic contrast since the DC component represents the area of the complete pulse. For dynamic contrast evaluation however we have to separate two subsequent frame periods as shown in fig. 5.

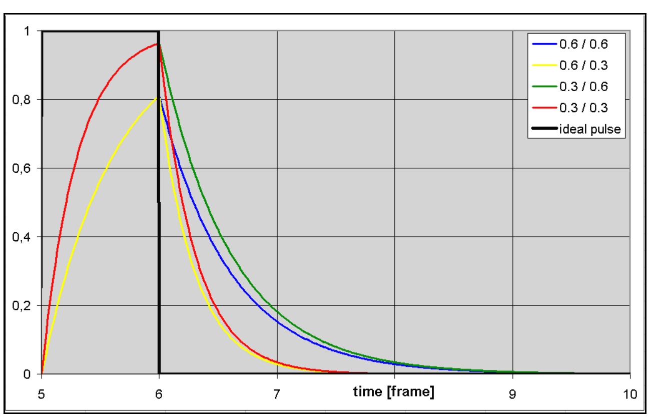


Figure 7: Exponential single-shot impulse responses calculated for 4 combinations of time constants of 0.3 and 0.6 T_F for rising and falling edge respectively.

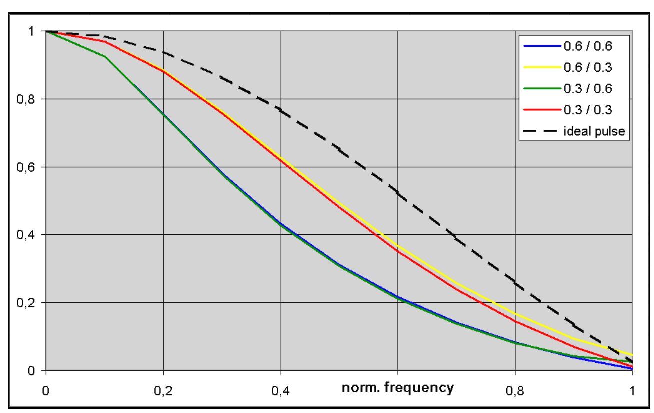


Figure 8: Modulation transfer functions for the impulse responses of fig. 7. The –3 dB bandwidths of red and yellow pulse and their MTFs are much alike, but dynamical contrast (modulation) is not.

5 Discussion

All considerations in motion analysis can either be done in the spatial [7] or in the temporal domain [5, 9]. We have chosen the temporal domain due to its convenient accessibility with respect to measurements. The test patterns considered here are regular arrays (grille, lattice) with rectangular cross-sections in order to realize the highest possible spatial frequencies. Sine-burst patterns as used in [6, 7] have to be approximated by piecewise constant step-functions and they thus comprise only a limited range of spatial frequencies. The *periodic impulse responses* on which our evaluations are based represent the most demanding performance case for the display under test and it is of pronounced significance when the impulse response is a function of the previous state of the system and when it is distinctly asymmetric as is the case for LCDs (see fig. 4).

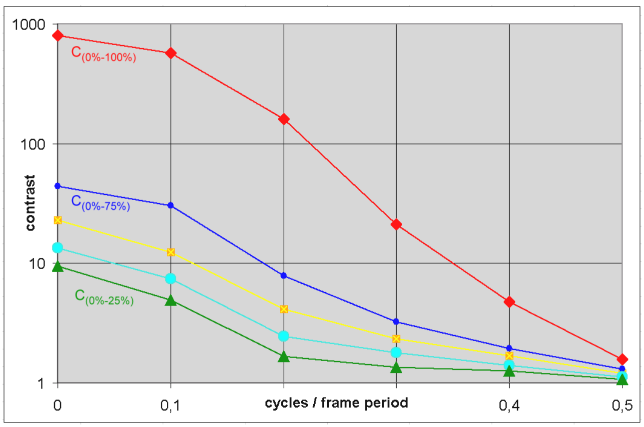


Figure 9: Variation of contrast for several combinations of input signals (0%, 25%, 50%, 75% and 100%) as a function of the number of transitions per frame period (typical example). The static contrast is plotted on the y-axis (zero cycles per frame period) and the case of the *periodic impulse response* is plotted at 0.5 (i.e. 1 cycle per two frame periods).

A detailed characterization of the dynamic performance of a display under test is obtained when the periodic change of driving signals from a first state to a second is varied in its duration and the resulting dynamical contrast (1) is evaluated as a function of the cycles per frame period. Two temporal conditions (1 cycle per 2*20 frame periods and 1 cycle per 2 frame periods) for three combinations of driving signals (25%-50%, 50%-75% and 75%-100%) are shown in figs. 6. For the extreme case of half a cycle per frame period the *dynamic contrast* introduced as worst case condition above is obtained and with increasing number of frame periods per (symmetric) driving signal the static contrast, C_{stat} is approached. These variations of contrast with the number of transitions per frame period is exemplarily shown in fig. 9 for 5 combinations of driving signals (0%-25%, 25%-50%, 50%-75% and 75%-100%). One transition per frame period equals one cycle per two frame periods.

This characterization of dynamic display performance is restricted to the display device itself, it does not consider specific properties of the human visual system like *smooth pursuit eye tracking* with temporal integration.

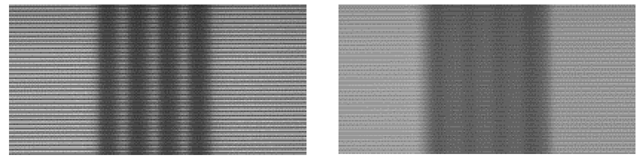


Figure 10: Illustration of the image of a horizontally moving array of 4 vertical dark lines on a bright background as taken with a tracking or with a high-speed camera [6].

Left: The DUT impulse response is fast enough to produce a noticeable contrast between the moving lines and the background.

Right: The DUT impulse response is too slow to produce a noticeable contrast between the moving lines and the background.

6 Conclusion

The presented method for evaluation of the contrast of moving lattice (grille) patterns does not require the efforts of imaging data acquisition with tracking or oversampling high-speed cameras followed by image analysis as described in [7]. We obtain the contrast of various test-patterns simply via measurement of the *periodic impulse response* of the display in the stationary state followed by integration of the luminance vs. time functions shown in fig. 6B over a period of width T_{Frame}. A rating of the visibility of the moving patterns can be performed in a subsequent step based on suitably chosen *contrast sensitivity functions* for moving patterns [e.g. 13]. It thus becomes possible to distinctly separate display properties from that of the human visual system.

We characterize the dynamic performance of display screens with moving grille patterns of any wavelength (pitch), arbitrary gray-levels and speed of translation by measurement of the temporal luminance variation at a fixed location with a suitable temporal sequence of test patterns obtained by transforming space into time along the motion trajectory of the moving target. This approach is attractive due to the reduced instrumental efforts (only a fast optical transient recorder is required, e.g. OTR-3 [10], and the transparency of the different steps of evaluation.

References

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