Characterization of one Time-Sequential Stereoscopic 3D Display - Part I: Temporal Analysis -

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Abstract

A method of characterizing time-sequential stereoscopic 3D displays based on the measurement of the temporal behavior of the systems vs. the grey levels is proposed. An Nvidia 3D vision kit with a 3D-ready SAMSUNG 2233RZ LCD display is characterized in the paper. OPTISCOPE SA especially designed for the precise measurements of the luminance and temporal behavior of LCD displays was used. The transmittance and response time of the shutter glasses was first evaluated. Then the grey-to-grey response times of the display were measured. The 2D and 3D behaviors of the display were then compared. Finally, the temporal behavior of the complete system was modeled, and the grey-level variations on one view were deduced as a function of the synchronization and level of the other eye. The main sources of imperfection were identified and quantified, and a full computation of the system performances was done.

Keywords: Shutter Glasses, Response Time, Grey Levels

1. Introduction

Optical characterization of 3D displays is mandatory for the quality control and comparison of different technologies. A new viewing-angle instrument was recently proposed by these authors for the characterization of autostereoscopic displays [1-3]. With this instrument, left- and right-eye and 3D contrasts can be computed everywhere in front of the display, and qualified monocular and binocular viewing spaces can be evaluated. It was shown that the same parameter can be calculated for polarization-based stereoscopic 3D displays [4-6] using multispectral polarization measurement with a Fourier optics viewing-angle instrument. A direct comparison of the two technologies becomes possible as similar quality parameters can be deduced. These authors are interested in the third class of the most popular 3D displays, the time-sequential stereoscopic 3D displays. This display technique has a long and successful history with CRT displays. Only recently was the LCD refresh rate increased to 120 Hz and even to 240 Hz to allow this type of technology.

Surprisingly, there are very few characterization results on this type of display in the existing literature. A. Woods studied the compatibility of LCDs with time-sequential stereoscopy but did not deduce the quantitative performances of the different methods (black-frame insertion, 120Hz refresh and modulated backlight) [7-8]. The 3D crosstalk has been measured for active glass 3D PDP TVs [9] and optically compensated time-sequential stereoscopic 3D LCDs [10-11]. Nevertheless, this quantity is being evaluated only for white-to-black transitions, whereas worse properties are always observed for grey-to-grey transitions. In addition, the respective impacts of the shutter glasses and displays have not been clearly identified. The time-sequential stereoscopic 3D TV has seen innovations of late, with ultrahigh-frequency 240Hz LCD solutions [12] or 120Hz LCDs with a dynamic LED backlight [13]. The improvement of the shutter glasses has also been proposed [14]. 3D active glass HDTVs will be available in the market this year (2010). This makes the precise optical characterization of such displays mandatory. In the following sections, a method of qualifying time-sequential stereoscopy displays will be proposed based on a precise grey-to-grey response time analysis of the display alone and combined analysis with shutter glasses using their measured transmission properties. This will allow the impact of the system's different imperfections to be evaluated for various grey-level transitions, and the overall quality of the system to be deduced.

Manuscript Received April 17, 2010; Revised June 3, 2010; Accepted for publication June 8, 2010

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2. Experiment Conditions

2.1 Response time measurement system

For the temporal measurements, the Optiscope SA instrument, which looks like a conventional camera, was used. An imaging objective collects the light within an angular aperture of ±1°, following the VESA standard. Optiscope SA can be used at various distances from the display, until 30 cm. An image of the target can also be obtained with a 1M-pixel color CMOS sensor, for alignment purposes. Half of the light goes onto a photomultiplier across a photo peak filter. The electronics include a 16bit analog-to-digital converter and an on-board 4Mb memory. A USB2.0 connection with a PC allows unlimited acquisitions with a sampling step between 5 and 20 µs. The dark noise was corrected using a shutter. The performances were measured using a computer-driven LED source. The signal-to-noise ratio was around 100 dB, and the repeatability of the response time measurements was less than 0.1% within the 1-100 ms range [15-16]. The system also includes a calibrated photodiode and internal LED illumination to allow self-calibration and accurate luminance measurements with the photomultiplier. For the grey-to-grey response time measurements, the Optiscope SA software automatically drives the display, adjusting the top and bottom grey levels in the 3D mode. The shutter glasses' transmittance and response times were also measured using Optiscope SA and ELDIM-stabilized LEDSource.

2.2 Time-sequential stereoscopic 3D display

In this paper, a commercial time-sequential stereoscopic 3D system composed of an NVIDIA 3D vision system and a Samsung SyncMaster 2233RZ 3D-ready 120Hz LCD display is characterized. The NVIDIA 3D vision system uses liquid crystal shuttered glasses synchronized with a display refresh rate of 120 Hz. Every 8.33 ms, the display switches from left- to right-eye view, or the opposite. The shutter glasses for the right or left eye are open for less than half a frame when the left- or right-eye view is stabilized on the display. It is obvious that the overall optical performance of the system will depend on the quality of the different components (the transmittance and response time of the shutter glasses, the response time of the display in the 3D mode, and the synchronization). In the following sections, the different components will be measured separately, and the temporal behavior of the combined system will be analyzed. As typical LCDs show a slower response for near-grey-to-grey transitions, a decision was made to conduct the study vs. the grey level, which is clearly the major parameter for such displays (as angular behavior is the major parameter for autostereoscopic 3D displays, or polarization behavior for polarization-based stereoscopic 3D displays). In particular, the response times of the LCD display in the 2D and 3D modes were analyzed.

3. Experiment Results

3.1 Characterization of the shutter glasses

The shutter glass transmittance was measured using the unpolarized white light emitted by an ELDIM LED-Source and the OptiscopeSA system. The measurement was normalized using the luminance measured without glasses. The temporal transmittance is shown in Fig. 1. The maximum transmittance that was reached in one frame was around 27%, and the contrast was around 600. As such, if the contrast is excellent, the maximum transmittance will be about two times less than the best theoretical value (50%). This relatively small transmittance value can be attributed to the fact that the light source that was used for transmittance measurement was completely unpolarized. In practical situations, the light emitted by the LCD display is generally linearly polarized. As such, if the liquid crystal of the shutter glass is properly aligned with the LCD, the maximum transmittance can be greatly increased (ideally by a

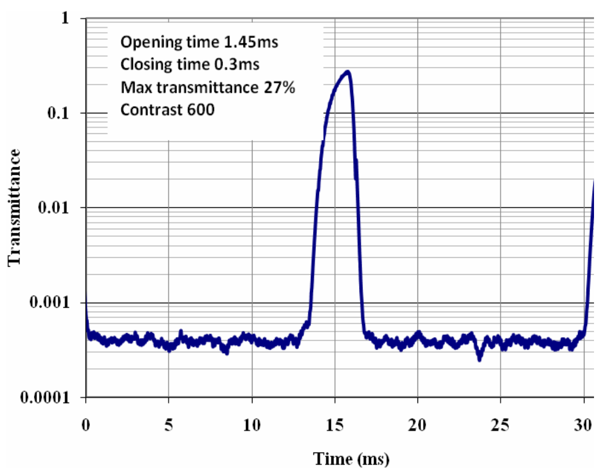

Fig. 1. Measured transmittance of the shutter glasses using white-light illumination.

factor of two). In addition, the response time of the shutter glasses is not very short. Even if the nature of the shutter glasses proposed by NVIDIA is not known, these results are compatible with a nematic liquid crystal shutter, where the off-state is obtained rapidly by applying an external voltage (response time: 0.3 ms). Conversely, the on-state corresponds to a null voltage and is obtained via nematic relax due to the restoring torque (response time: 1.45 ms). Other types of liquid crystal cells can have substantially better response times [14].

3.2 Characterization of the 3D-ready LCD display

The Samsung LCD display can be driven in two modes: the 2D mode, using DVI control at a low frequency, and the 3D mode, at a high frequency, using an NVIDIA graphic board. In principle, the 3D mode decreases the response time, blur, and crosstalk effects (the response time accelerator RTA is discussed in ref. [17]). In practice, an overdriving control unit with a lookup table is used, which depends on the previous frame level. The 2D and 3D modes do not have the same lookup tables. Using OptiscopeSA, grey-to-grey response time measurements were done in the two modes. For the 2D mode, a DVI connection, an ELDIM FPDLite pattern generator, and 8 Hz blinking frequency were used. For the 3D mode, the NVIDIA software provided with a video board was directly used. Each grey-to-grey temporal behavior was adjusted using simple rising and falling models, based on the transmittance of the crystal cell [16]. The time-dependent luminance variations for the rising and falling conditions were calculated using the following formula:

$$Y(t) = Y_{GL1} + (Y_{GL2} - Y_{GL1})\sin^2\left[\frac{\pi}{2}(1-\exp(\frac{-2t}{\tau_R}))\right],$$

$$Y(t) = Y_{GL2} + (Y_{GL1} - Y_{GL2})\sin^2\left[\frac{\pi}{2}\exp(\frac{-2t}{\tau_F})\right],$$

where Y_{GL1} and Y_{GL2} are the low and high grey-level luminance levels, respectively, and τ_R and τ_F the time constants for the rising and falling conditions, respectively. In practice, a transition measurement is made for approximately 10 periods, and the rising and falling regions are averaged. An adjustment is made in each averaged region using the Levenberg-Marquard algorithm, which provides the time constants, luminance levels, and uncertainty of all the values. An example of the adjustment for the transition between grey-levels 127 and 223 in the 3D mode is shown in Fig. 2. The full results for the 2D mode at 8 Hz and for the 3D mode at 120 Hz are shown in Fig. 3. In the 2D mode, the 8 Hz frequency was arbitrarily chosen, but it was found that the results did not change for the frequencies within the 1-40 Hz range. In the 3D mode, 120 Hz was the frequency recommended by the constructor. As expected, a reduction of the response time was noticed in the 3D mode but not in the 2D mode, and in particular, for the falling transitions from the levels near 255. Nevertheless, the average value for the response time was around 4 ms, which is not negligible when the shutter glasses blink at 120 Hz. The meas-

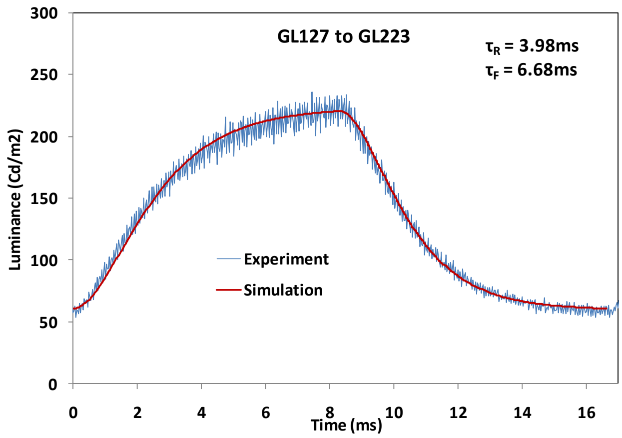

Fig. 2. Experimental and simulated temporal behavior for the GL127-to-GL223 transition in the 3D mode at 120 Hz. The fitted rising and falling time constants are shown.

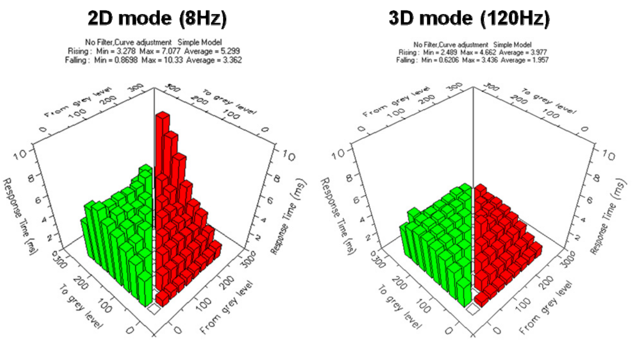

Fig. 3. Grey-to-grey response time measurements in the 2D mode (8 Hz) and 3D mode (120 Hz). The response times are defined from 10 to 90% of the signal. The green and red bars indicate the rising and falling transitions, respectively.

ured response times were used for the temporal analysis of the time-sequential 3D system. The direct fitting of the temporal measurements provided not only the response times for the different transitions but also the luminance level targets $YL^T{}_P$, which vary depending on the targeted and previous grey levels.

$$YL^T{}_{P} = Y_{GL2} \text{ for a rising transition, and}$$
$$YL^T{}_{P} = Y_{GL1} \text{ for a falling transition}$$

A summary of the results obtained for the Samsung display is presented in Table 1. For the intermediate grey levels, strong variations can be observed. The example of grey-level 127 is shown in Fig. 4. When the previous grey level was lower than 127, the target level was higher than the static 127 level. The opposite happened when the previous level was higher than 127. Combined with the shutter glasses, these grey-level target variations help obtain more stable light levels (RTA correction). The idea is to compensate for the time response effect through a different grey-level target, to stabilize the light level integrated across the shutter glasses for the same grey level.

3.3 Temporal-behavior simulation

The simulation method that was used is shown in Fig. 5. For each grey-level transition, the integrated luminance seen across the two glass shutters was calculated using the data measured with OptiscopeSA on the display alone, and the experimental temporal transmission of the shutters. $Y^T{}_P$ and $Y^P{}_T$ were the light levels seen across the shutter glasses for one eye seeing the targeted level when the other saw the

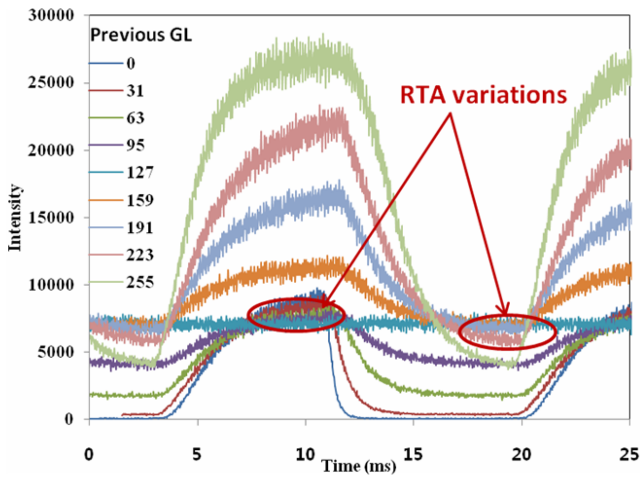

Fig. 4. Measured signal to reach grey-level 127 from the other grey levels in the 3D mode (120 Hz). The targeted variations are due to the RTA.

previous level and the opposite. The only parameter of the simulation was temporal delay δ, which was used to synchronize the luminance temporal behavior and the shutter glasses. Temporal delay δ is defined as the time between the start of the LC transition from a low to a high grey level and the start of the opening of the shutter glass supposedly to see the high grey value. This temporal delay is important because, in practice, it varies depending on the vertical position of the emissive pixel. This means that the light seen across the shutter glasses will depend on the grey level on the other eye and on the vertical position on the display. The results of the simulation that was performed using a temporal delay of 4.2 ms are summarized in Table 2. The value of δ was fixed to match the measurements that were

Table 1. Measured luminance level targets for the different grey-level transitions (the variations are due to the RTA)

	Grey Level target								
Previous Grey level	**0**	**31**	**63**	**95**	**127**	**159**	**191**	**223**	**255**
0	0.30	4.30	23.13	54.57	90.87	138.93	194.00	238.17	273.88
31	0.28	4.20	20.25	48.64	85.08	128.48	182.42	234.60	273.79
63	0.32	3.88	19.31	45.46	78.82	124.37	179.64	231.61	273.71
95	0.34	3.80	18.71	44.05	75.60	119.17	171.92	221.70	271.54
127	0.39	3.60	17.86	41.64	72.09	115.02	166.91	223.12	270.72
159	0.43	3.68	16.59	39.42	71.71	113.49	163.01	221.93	270.81
191	0.46	3.37	16.35	38.35	68.31	107.53	161.89	214.70	253.62
223	0.50	2.60	14.20	32.21	59.60	100.42	157.72	217.09	259.17
255	0.63	2.00	10.81	23.35	42.38	69.57	125.82	200.90	269.66

Table 2. Computed luminance levels across the shutter glasses for different grey-level transitions (temporal delay δ was fixed at 4.2 ms)

	Grey level seen across shutter glasses								
GL on the other eye	**0**	**31**	**63**	**95**	**127**	**159**	**191**	**223**	**255**
0	0.015	0.214	1.108	2.519	4.092	6.154	8.591	10.823	13.122
31	0.015	0.213	0.990	2.279	3.850	5.684	8.005	10.522	13.098
63	0.020	0.200	0.979	2.215	3.680	5.601	7.935	10.336	13.088
95	0.025	0.200	0.962	2.233	3.680	5.553	7.760	9.934	13.036
127	0.033	0.196	0.934	2.144	3.654	5.560	7.760	10.165	13.073
159	0.042	0.207	0.879	2.075	3.724	5.753	7.854	10.333	13.190
191	0.051	0.200	0.891	2.088	3.639	5.596	8.207	10.345	12.443
223	0.061	0.172	0.846	1.868	3.725	5.503	8.123	11.005	13.048
255	0.076	0.155	0.718	1.539	2.690	4.190	6.819	10.430	13.671

Table 3. Measured luminance across the shutter glasses for different grey-level transitions, using a SR3 spectrophotometer (the measurement was made near the display center)

	Grey level seen across shutter glasses								
GL on the other eye	**0**	**31**	**63**	**95**	**127**	**159**	**191**	**223**	**255**
0	0.012	0.171	0.953	2.383	4.103	6.444	8.642	11.118	12.094
31	0.014	0.144	0.793	1.995	3.723	5.760	8.364	11.014	13.712
63	0.018	0.142	1.098	2.383	4.097	6.153	8.445	10.636	12.978
95	0.024	0.140	1.047	2.175	3.670	5.655	7.929	10.248	13.152
127	0.031	0.142	1.048	2.094	3.390	5.366	7.816	10.448	13.324
159	0.040	0.151	0.986	2.004	3.408	5.329	7.845	10.406	13.894
191	0.050	0.156	0.926	1.926	3.265	5.308	7.728	10.500	13.638
223	0.063	0.139	0.832	1.651	2.974	4.983	7.446	10.790	13.648
255	0.077	0.131	0.625	1.303	2.336	3.932	6.545	10.504	13.964

made at the display center using a spectrophotometer (cf. 3.4). Other temporal delays yielded very different luminance levels for most of the grey-level transitions. The comparison of the values obtained for δ=4.2 ms with the luminance observed without shutter glasses revealed that the efficiency of the shutter glasses is very low (between 4.5 and 12%, depending on the grey-level transition). This is a general drawback of this type of time-sequential display. The reduction is due to the fact that only half of the time can be used for one shutter (factor two) and that the shutter cannot be open during image transition (again, factor two), and takes into account the transmittance properties of the shutter glasses. Another important observation is that, in spite of the RTA correction, the grey levels are not stable and depend strongly on the grey level on the other eye. It is particularly sensitive for grey-level 0, where the light pollution due to the other view can increase the signal by a factor of five.

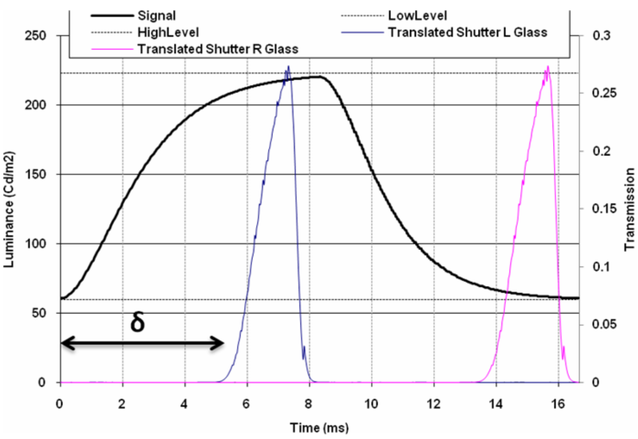

Fig. 5. Principle of the temporal simulation from GL127 to GL223. The temporal-luminance signal is integrated across the left- and right-eye shutter glass transmittance. The luminance across shutter glasses Y^{P}_{T} and Y^{T}_{P} was deduced. δ is the temporal delay.

3.4 Comparison with direct measurement across the glass shutters

To verify the feasibility of the proposed temporal model, the luminance of the display across the glass shutters was directly measured using a spectrophotometer. If the angular aperture of the spectrophotometer will be sufficiently reduced, the integration time will become much longer than the frame time and the uncertainty as the lack of synchronization between the spectrophotometer and the shutter glasses will be low. A Topcon SR3 spectrophotometer with a 1° angular aperture was used, and the measurements were made near the display center. A summary of the results is presented in Table 3. The comparison of these results with the simulation data in Table 2 obtained for a temporal delay of 4.2 ms revealed that the agreement is good for most of the grey-level transitions.

4. Conclusions

Presented for the first time herein are the results of a full temporal analysis of a time-sequential stereoscopic 3D display system. The properties of the shutter glasses and of the LCD display were studied separately. The response time of the LCD display was measured both in the 2D and 3D driving modes, for each grey-level transition. As expected, it was found that if the 3D mode is more rapid than the 2D mode, the luminance of the different grey levels will be modified depending on the previous grey-level value (RTA correction). These luminance variations associated with the same grey level are not the same for the 2D and 3D modes and can be very important for most of the grey-level values. Then the temporal behavior of the 3D mode was used to compute the luminance seen across each shutter glass. The parameters that were used were the grey levels on each eye and the temporal delay between the pixel refresh and the shutter glasses. The computation results using a temporal delay of 4.2 ms fully coincide with the results of the direct measurements that were made using a spectrophotometer at the display center.

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