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Analysis of response time characteristics for gaming display at various refresh rates

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ABSTRACT

Variable Refresh Rate(VRR) technology has become an important feature as gaming market grows. Also, response time is an important factor in gaming environment. In this paper, the response time of LCD gaming monitor and OLED gaming monitor was measured at VRR environment and the phenomenon was analyzed. LCD gaming monitor showed different response time values at various refresh rates, while there is no significant difference in response time at various refresh rates in OLED gaming monitor.

1 Introduction

A traditional display could be operated at a fixed refresh rate in the past[1]. But now, the display which supports the technology named VRR can be run at various refresh rates. Generally, VRR technology is used in game environment. When VRR technology is used, the driving refresh rate is changed at every moment. As the driving refresh rate changes, the display should have the same characteristics so that users will not be affected when playing the game. Among the gaming display characteristics, response time is one of the core parameters in game environment[2]. In addition, unlike other multimedia applications like video streaming and video download, video game is a highly interactive application, demanding very fast response time. Also, a slow response time can hugely affect the display of motion video as well as the ability of following a moving cursor[3,4].

The response time of a display describes how fastly the display can transit from one image to another image. The response time is often referred to as the time from 10% to 90% of the initial and ending relative luminance level[5]. The test pattern transiting speed should be slow enough to ensure that the output luminance shows the steady-state[6].

LCDs are very nature slow for transitions between certain luminance levels[3]. The response time for lower gray-to-gray transitions can be much larger than the black to white response time. Also, slow transition leads to smearing on moving images. For this reason, LCDs utilize the overdrive technology.

Various studies have been conducted on display response time such as about different pattern size, about motion blur and LCD PWM so on.[6] But these studies generally were conducted at a fixed refresh rate. As VRR technology has made a lot of progress, this paper introduces the comparison of the response time for the LCD gaming display with overdrive technology and OLED gaming display at various refresh rates in VRR mode, then analysis of the phenomenon.

2 Measurement

2.1 Environment Set-up

Two types of display were used, one is 49” 5120x1440, LCD gaming monitor with a maximum refresh rate of 240*Hz* and overdrive technology, and the other is 48” 4K OLED gaming monitor with a maximum refresh rate of 120*Hz*. Both of them support VRR technology and were set to default mode. *NVIDIA Geforce RTX 3080* graphic card was used for operating VRR technology.

2.2 Measurement Set-up

A Gray-to-Gray(GtoG) 9x9 matrix is used for this measurement, which means there are 72 test cases. For each test case, the rising time and falling time are measured and each test is the duration from when the transition is 10 to 90%. The final result of measurement is the average of the 72 GtoG times.

For the test pattern, Fig. 1 shows the test pattern used in this test. 10% test pattern was designed according to *Video Electronics Standards Association(VESA) Adaptive Sync Display Certification Test Specification*[7]. Background of the test pattern was set to 127 gray-level(8bit) because the peak luminance of both gaming monitors is less than 1000 cd/m^2. The program used for *VESA* HDR evaluation was used. (version. 0.968). The number of switching frame of this test was set to 3 frame which means the test pattern was changed every 3 frames.

For measurement, luminance colorimeter (RD-80S, Topcon, 2 degree aperture size) and oscilloscope (MSO9404A, Agilent) were used. Measuring distance was 50*cm* in darkroom. The number of captured data was 100*k* samples/ second and the high resolution was

applied.-

Fig.1 Image of test pattern

Fig. 2 shows an example waveform of response time with overdrive. According to waveform, the overshoot can be calculated. Equation (1) shows the overshoot calculation formula.

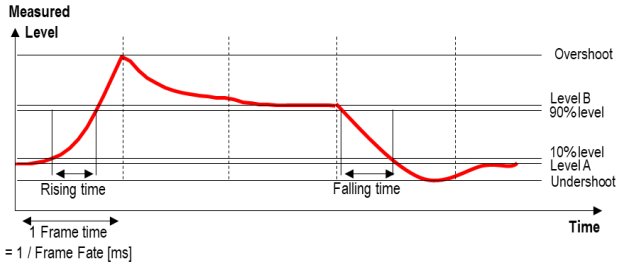


Fig. 2 An waveform of response time with overdrive

$$Overshoot = \left(\frac{level_{max} - level_B}{level_B - level_A}\right) x\ 100\% \quad ....(1)$$

2.3 Data Analysis

In order to find 10% and 90% level of relative luminance the steady-state luminance level, which means luminance level in a stable state, was calculated. The response time and overshoot were analyzed by Matlab (R2019b).

The overdrive effect should be considered for analyzing LCD gaming monitor. To avoid overdrive effect, the response time was calculated by using steady-state luminance.

For analysis of OLED gaming monitor, the overdrive is rarely used because OLED gaming monitor has a fast response time.-

3 Results

3.1 Response time of LCD Gaming monitor

Response time was measured and the value of overshoot was calculated based on measured data in 4 refresh rate cases. All of the results are shown in Table.1. In the result, Average GtoG means the average value in 72 cases. For overshoot, there are 36 overshoot cases per evaluated refresh rate. Average overshoot means the average value in 36 cases. In case of LCD gaming monitor, there are some differences in the value of average GtoG and average overshoot at measured refresh rate. It has the fastest average GtoG response time at 240*Hz*. In 36 cases, the gray-level from 0 to 31 has the largest overshoot value at 4 refresh rate cases.

Table. 1 Measurement result of LCD gaming monitor

Type	Refresh rate	Average GtoG	Average Overshoot
LCD gaming monitor	240Hz	1.7ms	25%
	120Hz	2.4ms	14%
	100Hz	2.5ms	18%
	60Hz	2.5ms	14%

Fig. 3 shows the gray-level from 0 to 31 and Fig. 4 shows the gray-level from 191 to 255 rising time and falling time of measured waveform of LCD gaming monitor at 240*Hz* respectively. The rising time of the gray-level from 0 to 31 and the gray-level 191 to 255 gray-level was three times different. The falling time of two cases are similar. In the case of overshoot from 0 to 31 gray-level case has the largest overshoot and is about 99%.

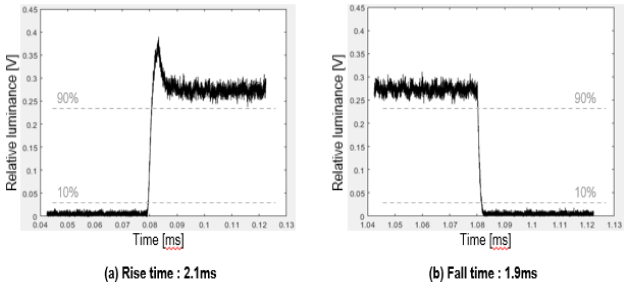


Fig. 3 Waveform of the gray-level from 0 to 31 of LCD Gaming monitor at 240*Hz*

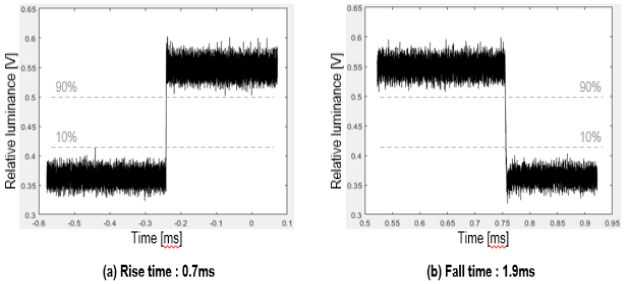
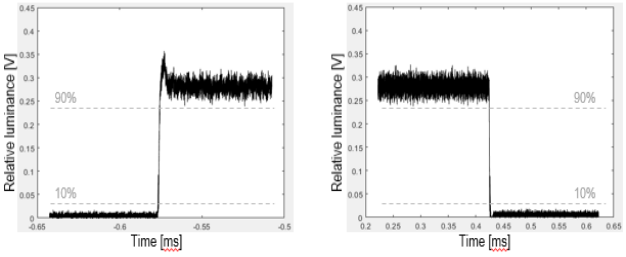


Fig. 4 Waveform of the gray-level from 191 to 255 waveform of LCD Gaming monitor at 240*Hz*

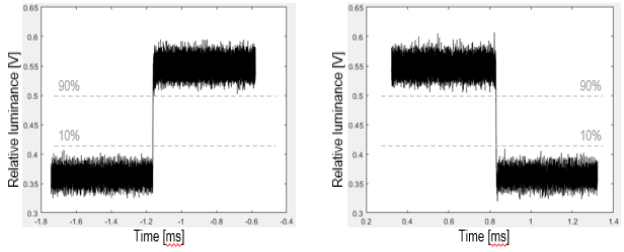
Fig. 5 and Fig. 6 show measured waveform of LCD gaming monitor at 60*Hz*. The trend of the value looks similar to the case of 240*Hz*. For response time, the value of the gray-level from 191 to 255 is almost three times larger than the case of the gray-level from 0 to 31.

For overshoot, in the case of the gray-level from 0 to 31 had the largest value of 58%.



(a) Rise time : 3.9ms (b) Fall time : 1.9ms

Fig. 5 Waveform of the gray-level from 0 to 31 of LCD Gaming monitor at 60*Hz*



(a) Rise time : 1.5ms (b) Fall time : 2.2ms

Fig. 6 Waveform of the gray from 191 to 255 of LCD Gaming monitor at 60*Hz*

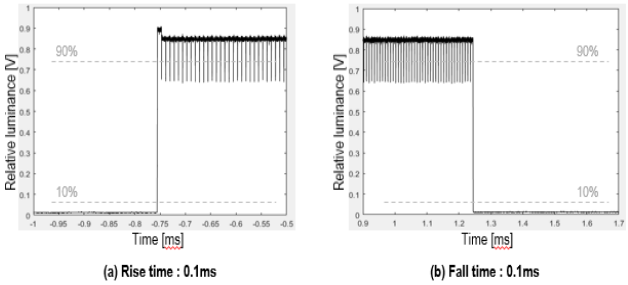
As a result of LCD gaming monitor, two significant characteristics were found. For response time, there are some difference depending on gray level. It may be due to the different level of overdrive. For overshoot, the case of the gray-level from 0 to 31 has the largest value and there is almost no overshoot when input signal reaches 255 gray level. The trend of result of response time and overshoot is similar for each refresh rate.

3.2 Response time of OLED monitor

Fig. 7 and Fig. 8 represent waveform of OLED gaming monitor at 31 gray-level and 255 gray-level test patterns. The measured waveform of OLED gaming monitor is simpler compared to LCD gaming monitor. In the case of OLED gaming monitor, there is less overshoot compared to LCD gaming monitor, also there is no significant difference between 120*Hz* and 60*Hz*. Rising time and falling time seem to have similar values.

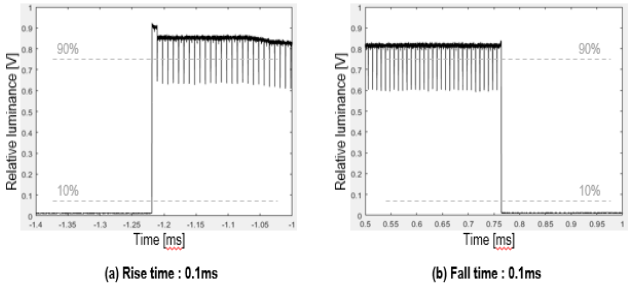
Table.2 Measurement result of OLED gaming monitor

Type	Refresh rate	Average GtoG	Average Overshoot
OLED gaming monitor	120Hz	0.1ms	7%
	100Hz	0.1ms	8%
	60Hz	0.1ms	7%



(a) Rise time : 0.1ms (b) Fall time : 0.1ms

Fig. 7 Waveform of the gray-level from 0 to 31 of OLED Gaming monitor at 120*Hz*



(a) Rise time : 0.1ms (b) Fall time : 0.1ms

Fig. 8 Waveform of the gray-level from 0 to 255 OLED Gaming monitor at 120*Hz*

4 Discussion

4.1 Overdrive technology and response time

Unlike OLEDs, LCDs which emits light through backlight has a slow response time relatively. To overcome this problem, LCDs usually use overdrive technology.

Overdrive technology usually is used using one frame buffer. Suppose there are three gray levels, *g1*,*g2* and *g3*.(gray level : *g3*>*g2*>*g1*>0) If there is a pattern changed from g1 to *g2* with overdrive technology, the first frame of the input signal is not *g2* but *g3*. If so, the display can reach the luminance of corresponding to *g2* much faster.

Overdrive technology affects the level of response time directly. The refresh rate of display is also very important because of using one buffer frame. When operating an LCDs in a fixed refresh rate, it may not be a significant problem. But when operating an LCDs in VRR mode, the frame time can be different for every frame. If overdrive is tuned for a fixed frame time like 8.3*ms* (120*Hz*), and the GPU is rendering at low frame rate, significant overshoots can occur. These overshoots lead to a visual phenomenon called 'negative ghosting'.[3] And it can also lead to a the difference of response time at various refresh rates. To resolve this problem, the level of overdrive should be tuned in every frame time respectively.

4.2 Horizontal line and response time

In this paper, the condition of measurement were fixed with 2 degree aperture of Light Measurement Device (LMD) at 50 cm of measurement distance. However, if the test distance, aperture size of LMD or panel size is changed, the response time could be also changed because of the horizontal line time of display which is required time to electrically address the horizontal data line of display [5, 8]. This phenomenon could appear more clearly in OLED gaming monitor than LCD gaming monitor, because OLEDs has as fast response time as the horizontal line time[5]. So, for OLED gaming monitor, the number of horizontal lines is more important when it comes to response time. As the number of lines is changed, the response time could be changed.

5 Conclusions

In this paper, the response time of the LCD gaming monitor and OLED gaming monitor was measured in VRR mode. For LCD gaming monitor, it was proved that the level of overdrive affects the response time and it can cause side effect such as 'negative ghosting' depending on tuning refresh rate. For OLED gaming monitor, in case of response time and overshoot, there were no difference in various refresh rates, but the response time has influence by horizontal line time. In this paper, only gray-to-gray response time was measured at 10% pattern size was measured at 10% pattern size in VRR mode. It is necessary to study about various color, size and the LCD gaming monitor with PWM driving in the future. In addition, as the VRR technology and display specification has developed rapidly, the measurement method for response time on international standard need to be improved.

References

[1] Nvidia G-SYNC VRR Technology https://pcmonitors.info/articles/nvidia-g-sync-vrr-technology

[2] LIU Sha, MA Shi-qing The Brief Trends Analysis of Gaming Display Device, International Conference on Display Technology 2021(Volume 52, Issue S2)

[3] Gerrit A Slavenburg, et al., Variable Refresh Rate, invited paper.

[4] Shaoxuan Wang, Sujit Dey et al. Addressing Response Time and Video Quality in Remote Server Based Internet Mobile Gaming, IEEE Communications Society subject matter experts for publication in the WCNC 2010.

[5] ICDM, Information display measurement standard, Version 1.03b, 10.2, Response-time metrics.

[6] H. E. Lee, J. H. Kim et al, Analysis of Response Time Characteristics between LCD TV and OLED TV, IDW21.

[7] VESA Adaptive-Sync Display Certification Test Specification, Revision 1.0, 7. Gray-to Gray Testing.

[8] ISO 13406-2, Ergonomic requirements for work with visual displays based on flat panels — Part 2: Ergonomic requirements for flat panel displays, 3.4.4, image formation time.