Characterization of one Time-Sequential Stereoscopic 3D Display
- Part II: Quick Characterization Using Homogeneity Measurements -

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Abstract

In these authors’ previous paper, it was shown that grey-level stability is one of the main drawbacks of the time-sequential stereoscopic 3D display. In the present study, it was demonstrated that a videoluminance meter can be used to rapidly and easily check the quality of such display. A dedicated pattern was applied to simultaneously check the effect of the grey level on the other eye and the effect of the temporal synchronization. The results were compared with those provided by a temporal model of the display, which was obtained by measuring its temporal behavior. The visual impact of the grey-level instabilities was precisely quantified, and they were found to be a major source of imperfections for the aforementioned display.

Keywords: Shutter glasses, grey levels, temporal synchronization

1. Introduction

With the rapid extension of the 3D display market for various applications, simple and accurate tests focused on the quality of the stereoscopic effect for the user must be developed. In any kind of 3D display, the stereoscopic effect is always obtained by providing different images for the right and left eyes of the observer. For autostereoscopic displays, the light emission directly provides different images at different locations in front of the display. If the observer is at the right location, the stereoscopic effect will be obtained. The qualified stereoscopic viewing space of such displays can be evaluated using viewing angle instruments [1-3]. An imaging instrument located at an adequate distance can also be used to check the light emission along the display surface and to evaluate the parasitic effects, such as moiré [4]. For polarization-based 3D displays that require the use of dedicated glasses to see the stereoscopic effect, the polarization state of the light emitted by the display can also differ depending on the location on the display surface and on the direction [5-6]. In the same way as in autostereoscopic displays, the qualified stereoscopic viewing space can be evaluated [7]. It was recently proposed by these authors that the overall quality of such display be checked using an imaging polarimeter located at the right front part of the display [8]. Using this technique, some “polarization MURA” defects can be detected on the display’s surface, which affect the stereoscopic perception by changing the crosstalk between the observer’s eyes [9-10].

The focus of this study was the third class of the most popular 3D display, the time-sequential stereoscopic 3D display. This display now uses high-frequency LCDs and shutter glasses and has become the first commercial solution for the domestic 3D TV. In these authors’ previous paper published in the same journal, the temporal behavior of such 3D solution was studied in detail [11]. The LCD and shutter glasses’ performances were measured separately and were combined in a temporal model to explain the grey-level variations that were observed on the aforementioned display type. Strong grey-level variations were observed depending on the grey-level value on the other eye, and on the temporal synchronization. These authors’ temporal model has been validated via direct measurement with a spectrophotometer. All these measurements were performed at one specific location on the display surface. The purpose of the present study is to introduce another method based on the use of an imaging luminance meter that allows the rapid measurement of the grey-level variations vs. the crosstalk between the two views and the temporal synchronization. The measurement was realized on the overall display surface.
2. Experiment Conditions

2.1 Time-sequential stereoscopic 3D display

Characterized herein is a commercial time-sequential stereoscopic 3D system composed of an NVIDIA 3D vision system and a Samsung SyncMaster 2233RZ 3D-ready 120Hz LCD display. 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 the left- to the right-eye view, or the opposite. The shutter glasses for the right or left eye are opened after less than half a frame when the left- or right-eye view is more or less stabilized on the display.

2.2 Imaging luminance meter and colorimeter

UMaster was used for the imaging luminance measurements. It is based on a Peltier-cooled CCD sensor with a true 16-bit analog digital converter. Four color filters dedicated to each CCD sensor are mounted on a motorized color wheel. A second motorized wheel with flat densities is also available for automatic adjustment to the source luminance. The imaging optics is telecentric on the sensor side. This means that all the light rays in the field aperture reach the sensor surface at normal incidence. On the contrary, for standard imaging optics, the light rays generally reach the sensor with an increasing angle when going outside the optical axis of the system. This telecentric configuration is especially important because the color filters located just before the sensor are then crossed at normal incidence, and the same spectral response is guaranteed on the entire sensor surface. In addition, the flux is quasi-independent of the object distance while the conventional optic can suffer from an up-to-20% reduction at a short distance [12]. Consequently, only one calibration is required for all the situations. The same system can be used for imaging polarization measurement at different wavelengths. One shutter glass is included before the entrance iris of the optical system. The angular aperture of the imaging objective and the size of the iris are fixed at values comparable to the human eye (angular aperture of ±16° and aperture iris diameter of 3 mm, respectively).

3. Experiment Results

3.1 Test pattern

To test the visual impact of the grey-level variations on one eye depending on the grey level on the other eye and vs. the temporal synchronization, it was proposed that the double pattern reported in Fig. 1 be used. In the 3D mode, the right eye is supposed to see a homogeneous display across the shutter glasses. In practice, however, due to the impact of the grey level on the left eye, some grey-level variations that depend on the grey level and on the temporal delay that varies along the vertical display appear on the right eye. The influence of the grey level and of the temporal delay on the other eye can be checked simultaneously with the proposed pattern.

![Fig. 1. Test patterns for the video-luminance meter measurements: (a) in the left view, vertical bands with different grey levels are displayed; and (b) the right view is homogeneous with a variable grey level.](image-url)
calculated and was compared to the static value (same homogeneous level on each eye).

\[
\Delta Y_T^P = \frac{Y_T^P - Y_T^T}{Y_T^T + Y_T^T}
\]  

(1)

\(Y_T^P\) is the light level seen across the shutter glasses for the eye that sees the targeted grey-level \(T\) when the other eye sees grey-level \(P\). \(Y_T^T\) is the luminance seen across the shutter glasses for the same level \(T\) on the two eyes. The normalization of the static value allows the elimination of luminance fluctuations due to the homogeneity problems on the display surface while keeping the variations due to the time-sequential mechanism.

In practice, for each target grey-level \(T\), this homogeneous level is applied on the image that is supposed to be seen with the homogeneity measurements, and two homogeneity measurements are done:

- one with the vertical band pattern reported in Fig. 1a on the other eye, to obtain \(Y_T^{\text{pat}}(x,y)\); and
- one with the same homogeneous-level \(T\) on the other eye, to obtain \(Y_T^{\text{hom}}(x,y)\).

Equation (1) then becomes:

\[
\Delta Y_T(x,y) = \frac{2Y_T^{\text{pat}}(x,y) - Y_T^{\text{hom}}(x,y)}{Y_T^{\text{pat}}(x,y) + Y_T^{\text{hom}}(x,y)}
\]  

(2)

The lateral variation gives the dependence vs. the previous-level \(P\) on the other eye. The relative grey-level variations for grey levels 0 and 127 are shown in Fig. 3 and 4 for the overall display surface. As expected, the relative grey-level variation depends on the other grey level (vertical bands) and on the temporal delay (vertical variation along a band). Strong variations up to \(\pm 170\%\) were detected for grey-level 0. For grey-level 127, the fluctuations were less important but can reach up to \(\pm 50\%\). The impact of interocular luminance differences on stereoscopic depth perceptions has been studied [13]. Even if depth perception can survive despite strong variations, the overall luminance level is also important. It has already been shown that depth perception is easier when the overall luminance level is high. Unfortunately, in the case of time-sequential displays, the low efficiency of the shutter glasses induces the strong reduction of all the luminance levels of the LCD display, and the impact of the luminance differences is maximized.

3.3 Temporal computation and comparison with the imaging results

All the details of the computation method are reported
in another paper in the same journal [11], and the computation method is illustrated in Fig. 5. The luminance temporal variation for each grey-level transition measured using an OptiscopeSA instrument was used. Then this temporal behavior was integrated across the two shutter glasses that were modeled using the experimental temporal transmission value measured using the same system and a static light source. For a given grey-to-grey transition, the unique parameter that was used was the temporal-delay $\delta$ between the LCD transition and the shutter transition. It is easy to understand that, taking into account the response times of the LCD and shutter glasses, the light seen across the shutter glasses varied strongly with this temporal delay. The previous imaging luminance measurement results can be completely explained by this temporal model. As shown in Fig. 6 and 7, the relative grey-level variation measured on the display surface for grey levels 0 and 127 can be completely computed using the temporal model reported above. The vertical-luminance variation observed on the LCD resulted from a variation of the temporal delay of about 6 ms.

**Fig. 5.** Principle of the temporal computation for the transition from grey-level 63 to grey-level 127: The LCD emission was deduced from the OptiscopeSA measurements, and the shutter glass transmittance pattern shifted depending on temporal delay $\delta$. GL1 and GL2 are the integrated luminance values observed across the left and right shutter glasses, respectively.

**Fig. 6.** Relative luminance variation for grey-level 0 measured using the luminance data in Fig. 3 (top) and simulated using the temporal model shown in Fig. 5 (bottom). The spot number on the top figure is directly related to the vertical position on the display surface.

**Fig. 7.** Relative luminance variation for grey-level 127 measured using the luminance data in Fig. 4 (top) and simulated using the temporal model shown in Fig. 5 (bottom). The spot number on the top figure is directly related to the vertical position on the display surface.

### 4. Conclusions

A quick characterization method for time-sequential stereoscopic 3D displays was proposed. The use of a dedi-
cated grey-level pattern allows the rapid and efficient measurement of the grey-level stability. The impacts of the grey level on the other eye and of the temporal synchronization were simultaneously evaluated. For the aforementioned display, the grey-level variations are certainly the main source of imperfections in terms of stereoscopic perception.

The overall luminance of the 3D system was also measured in the same experiment. As shown in Fig. 5, the luminance level that was obtained across the shutter glasses was very low compared to the level of the display itself. This lack of luminance is certainly the second main source of imperfections of such 3D displays. The occurrence of low luminance levels increases the perception of the grey-level fluctuations.

References