AR/VR Near-Eye Displays: Meeting their Distinctive Challenges in Display Quality Control

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ABSTRACT

Near-eye displays (NEDs) exhibit a number of effects including distortion and sharpness distribution due to the optics that generate the virtual image. We present why a spectrally enhanced camera based system such as the LumiTop is ideal for production testing of these displays.

1 Introduction

NEDs differ fundamentally from other displays in the consumer electronics area due to their proximity to the observer; the displays must account for the structure of the human eye and project a virtual image to it by way of complicated optics such as birdbath optics or diffractive waveguides. These optical systems must be precisely positioned and adjusted to avoid artifacts or deleterious optical effects that prevent immersion of the user in the virtual reality environment. NEDs can exhibit the whole assortment of defects present in conventional displays (Mura defects, nonuniformity in the luminance or color over the surface of the display, etc.) but also effects such as distortion or chromatic aberration that arise due to the specialized optical design. As these effects can vary over the field of view available to the user, they must be investigated with a 2-D measurement system to see the respective spatial variations and allow for their correction. These aspects are certainly of interest during qualification and development of new headsets, but are also relevant during production to ensure that each NED meets the high demands of both producer and consumer. Quality assurance of NEDs during production is also particularly challenging, as light measurement devices (LMDs) for testing must mimic the human eye as closely as possible. The LMD must, for example, measure as close to the eye's 120° FOV as possible, account for the variable entrance pupil and measure color and luminance with very high accuracy.

In this paper we present results from the LumiTOP with AR/VR lens, a 2D imaging LMD specially designed for production quality assurance of NEDs. It allows for a hybrid color and spectral acquisition for the highest accuracy in color measurement and the 2D images of color and luminance from the system are well suited to evaluating optical defects specific to NEDs. This allows measurement of parameters that, assuming the error is not too large, can be corrected with image processing (distortion, chromatic aberration), as well as effects that are intrinsic to the optical setup of the NEDs and cannot be corrected after assembly (sharpness distribution).

2 Experiment & Results

For 2D measurements, we used the imaging light measurement device LumiTop 4000 (by Instrument Systems) designed for display testing in production lines. Based on the well-known LumiTop concept[1], the presented test solution combines a 12 Megapixel RGB CMOS camera with the reference spectroradiometer CAS 140D. This feature provides an essential contribution to the achieved low level of measurement uncertainties, since knowledge of the spectral DUT information provides the means to correct for spectral changes in the measured light sources. A dedicated AR/VR lens for LumiTop imaging colorimeters is specifically designed for production testing of NEDs in virtual and augmented reality headsets. The optical design mimics the human eye and measures color and luminance exactly as seen by the user. A large field of view, various pupil sizes and adjustable focus distance enable a wide range of testing. The high measurement speed of the system[1] and its excellent accuracy of the system for luminance and color measurements of NEDs[2] has been previously proven.

We have conducted all experiments on an Oculus Go, a well-known virtual reality headset. The device has a field of view of around 100° and features an LCD display with a resolution of 2560×1440 pixels.

The localized distortion is evaluated by first loading the pattern indicated in Fig. 1(a) on the NED. The distortion is estimated by observing how far each blob position deviates from the ideal position. The ideal blob positions are calculated with the help of the central blobs positions and by assuming a uniform magnification factor across the image field.

The chromatic aberration is evaluated using a uniform white images with a regular pattern of black spots with as depicted in Fig. 1(b). The RGB nature of the camera in the LumiTop is employed to take independent red, green, and blue images of the test pattern. The value for the chromatic aberration is defined locally by analyzing the red and blue channels and calculating the displacement necessary to align each spot with the corresponding spot in the green image. The chromatic aberration is then plotted in a 3-D figure to identify areas of high and low chromatic aberration.

The sharpness across the image is identified by the slanted edge method on a pattern of slanted edges distributor across the image (Fig. 1(c)) and expressed in SFR values with a normalization frequency for sharpness of 0.15 cycles/px. The results from color images are evaluated and for each tristimulus value the results are presented and plotted separately.

3 Results & Discussion

Figure 2 shows a plot of the distortion of the image over the virtual image. The values are in the upper and lower left corners are considerably higher (over 4-6%) as compared to the other values in the across the image. Errors of this magnitude can often be corrected through processing of the source image[3].

Figure 3(a) and 3(b) show the chromatic aberration for the red and blue channels respectively. The chromatic aberration for the red channel is largely uniform in the center of the field of view, whereas the aberration in the blue channel is over 3 pixels for a significant portion of the field of view to the right. Transverse chromatic aberration was previously investigated in commercial AR/VR headsets[4], but the results were presented assuming the effect was radially symmetric. However, we see the images of the aberration are clearly not radially symmetric and a position and color dependent correction in post processing would be necessary to uniformly improve the performance of the display with respect to this effect.

Figures 4(a), 4(b), and 4(c) display the sharpness value in respectively for X-, Y-, and Z-channels in the image. All three channels show a relatively high sharpness in the center of the image (SFR > 0.25). The images of the sharpness show areas where the different color channels have significantly different sharpness; for example, directly below the image center at the edge of the FOV each color channel has significantly differently SFR values (~0.25 for the Y-Channel, ~0.12 for the X-Channel, and ~0.05 for the Z-Channel). This has significant impact on the optical experience of the user, and as it arise from the hardware of the NED, it cannot be corrected with by processing of the image but must be evaluated on a pass/fail basis.

4 Conclusions

We see in NEDs specialized artifacts and effects in the virtual image that are not present in conventional consumer electronics devices like tablets and smartphones, such as chromatic aberration or distortion. A 2-D LMD is required to adequately investigate the spatial variation of these parameters quickly enough to be suitable for production testing. The LumiTop AR/VR is ideally suited for this measurement task with it's 120° FOV and spectrally enhanced camera for high speed and accurate measurement of luminance and color maps of the virtual display. This allows quality assurance on a high level of that is both fast and accurate for current NEDs.

References

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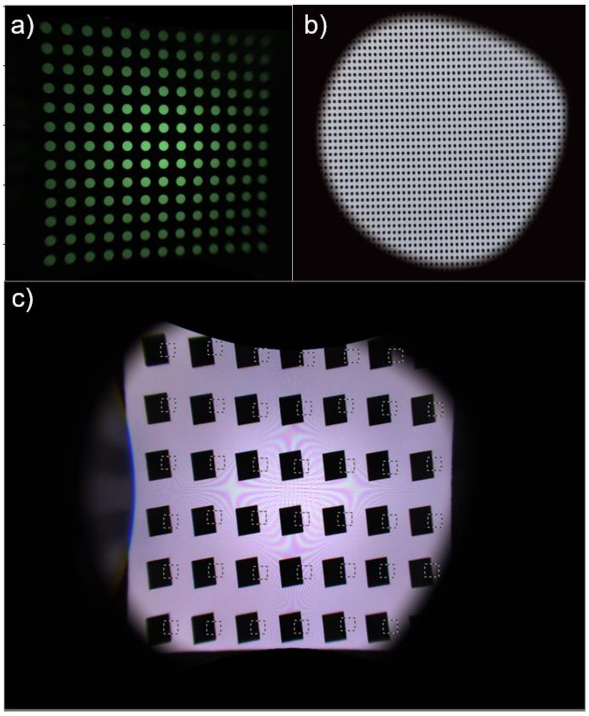

Fig.1: Test patterns for a) distortion, b) chromatic aberration, and c) sharpness distribution.

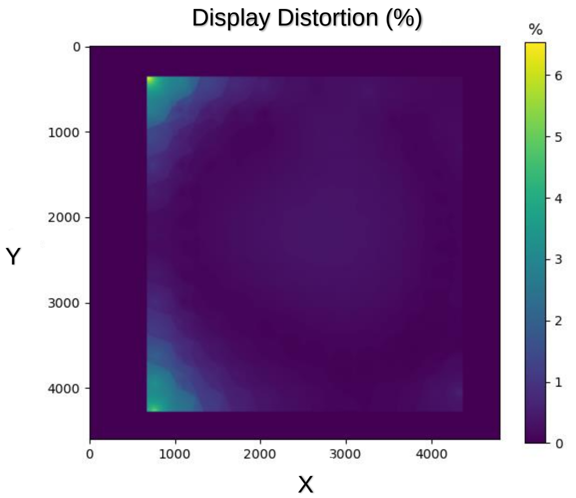

Fig.2: Distortion measurements of the virtual image. The axes correspond

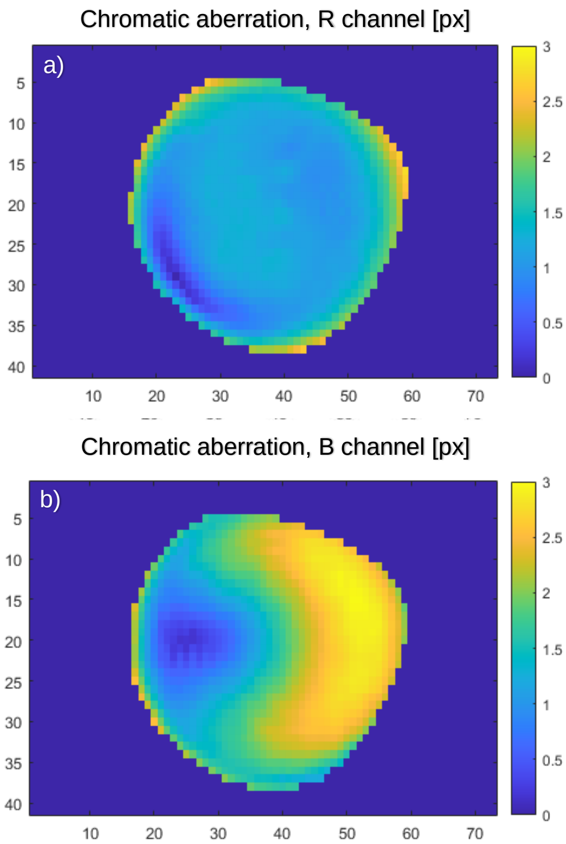

Fig.3: Chromatic aberration measurement of the red (R) and blue (B) channels are displayed in Figures a and b respectively. They are expressed in the term of spatial displacement compared to the corresponding green channel.

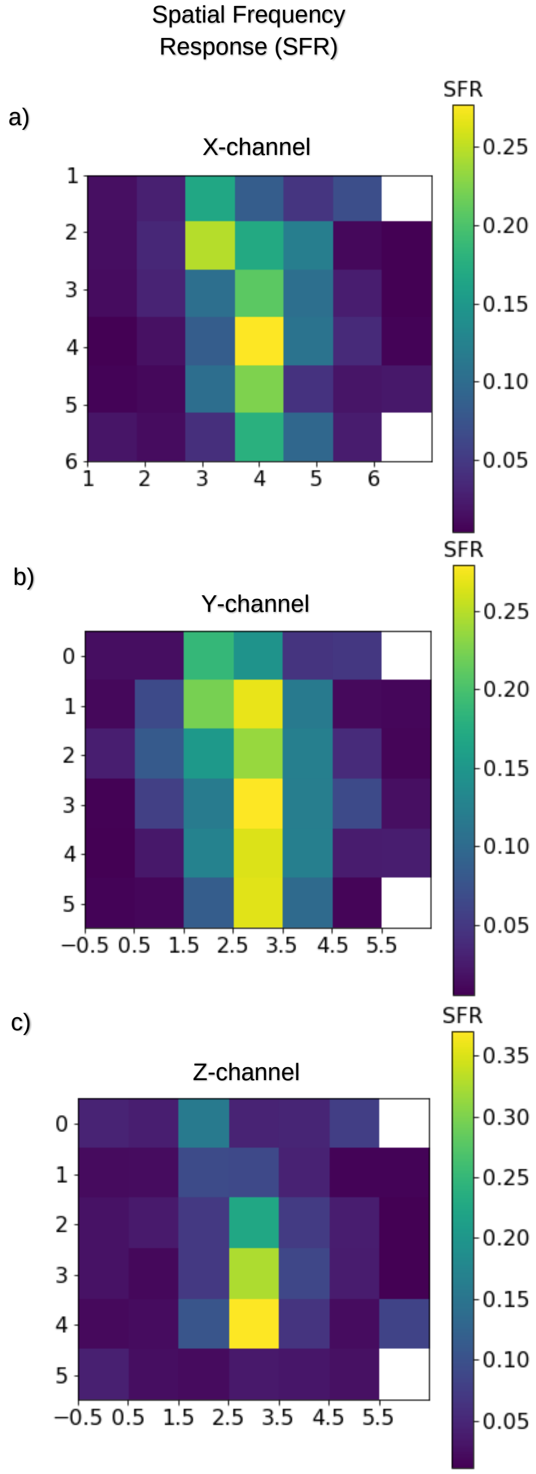

Fig.4: The spatial distribution of sharpness of the virtual image evaluated separately for the X-channel (a), Y-channel (b), and Z-channel (c).