User Manual:
Instructions on Implementing Head Mounted Display Eyebox Centering using Transverse Chromatic Aberrations

Tool Reference

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Instructions adapted from Section 19.3.5 of Information Display Measurements Standard, SID, 2023.

I. DESCRIPTION

The eye-point of a NED can be determined using the transverse chromatic aberrations (TCA) of the HMD. Transverse chromatic aberrations (TCA) are caused by the dispersion of the optics of the NED leading to a wavelength dependent magnification. TCA are minimized along the optical axis of the NED and can be used to determine the center of the eyebox. TCA is illustrated in Fig. 1a as an example. Units: none, Symbol: none

II. APPLICATION

This measurement has been applied to virtual reality NED that exhibit measurable TCA, such as wide field of view NED using Fresnel lenses. The method is intended to find the x,y eye-point location within the eyebox.

III. SETUP

This method uses a camera mounted on a three-axis stage to determine the eye-point position from the TCA. The TCA is measured using a fixed camera that images part or the full virtual image. TCA is measured using a pattern consisting of red, green, and blue bars one NED pixel wide displaced vertically by the height of the bar along the horizontal with a spacing of a few degrees in the field of view. The same pattern is used for the vertical direction, where the bars are displaced by the width of the bars in the horizontal direction (Fig. 1b). The camera should have sufficient resolution to resolve the bars as well as subpixel pattern in the NED in order to measure shifts in the bars by one NED sub-pixel. After acquiring an image, the location of the minimum TCA in the image is determined, which is the eyepoint of the eyebox. The camera can be moved to that location.

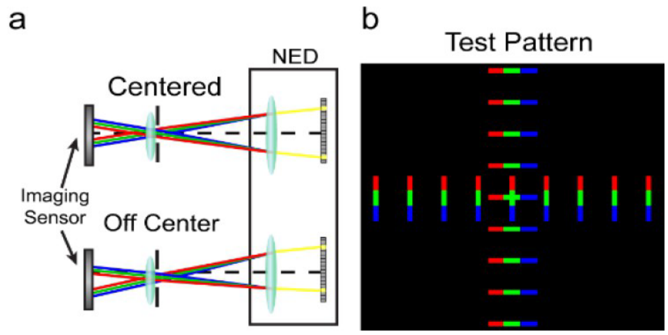

Fig. 1. a. Sketch of the setup for NED centered (top panel) and off center (bottom panel) in the eyebox. b. Example test pattern for TCA.

IV. PROCEDURE

The following procedure describes the experimental setup and image acquisition steps.

1. Set up the detector by aligning to NED with 25 mm eye relief + 3 mm to the LMD aperture stop of the entrance pupil.
2. Render a test pattern similar to the pattern shown in Fig. 1b on the NED.
3. Point the LMD viewfinder to center of the test pattern and set the point direction measurement angle to 0,0.
4. Acquire an image of the test pattern using the LMD.
5. Move LMD to a new x location in the eyebox.
6. Repeat steps 4 and 5 until x = + 2 mm from the starting point.
7. Move the LMD back to the start position and repeat steps 4 through 6 in the opposite x direction.
8. Repeat steps 4 through 7 in the + y and – y directions.

Note: To further improve the sampling of the HMD, the camera can be rotated by approximately 5 degrees relative to the display, which is similar to the slanted-edge response in ISO 12233-2023.

V. ANALYSIS

This method requires determining the TCA for a particular x,y position of the camera in the eyebox and repeating the measurement for other x,y positions.

The TCA of the NED is calculated from the location of the center of the red, green, and blue bars on the camera. This can be accomplished by taking the horizontal and vertical profiles for each colored bar across the image. To improve the signal-to-noise and average over the subpixel pattern, it is recommended to sum NED 25 pixels in the direction perpendicular to the measurement direction. In other words, sum NED 25 pixels in the vertical direction when determining the horizontal TCA for each colored bar.

The position of the red and blue bars relative to the green bars can be calculated using Δ x' r/b

= x' r/b – x' g,

Δ y' r/b = y' r/b – y' g,

where x' r,b,g and y' r,b,g are the x' and y' positions of the red, blue, and green bars on the camera. This can be reported in pixels or converted to distance. By calculating the displacement relative to the green bars, the monochromatic aberrations, such as distortion are normalized out of the measurements. In addition, the position of the green bars can be used as the ideal bar position without TCA. The data for Δ x' r versus x'g and Δ x' b versus x'g are fit with lines and the intersection of the two lines gives the location of the minimum TCA on the camera, which is the eye-point. Figure 2 shows example data of the intersection point shifting depending on the location of the camera in the eyebox.

These measurements can be repeated for different x,y locations in the eyebox to create a map of the eyebox where the color scale is the offset of the TCA minimum from the center location. Figure 3 shows an example of the eyebox map for the horizontal and vertical directions.

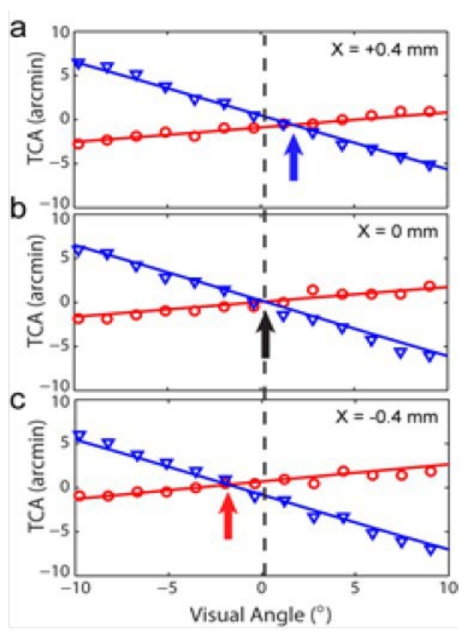

Fig. 2. TCA as a function of eyebox position with LMD displaced by a. 0.4 mm, b. 0 mm, and c. -0.4 mm in the horizontal direction.

I. REPORTING

Report the eye-point alignment method, the bar size and periodicity, method for determining the bar position, the raw angular dot positions, cross-section of the x and y directions of the TCA minimum across the eyebox.

COMMENTS

This method is intended to be used with NED with measurable TCA. It has primarily been tested on Fresnel-type virtual reality head mounted displays. The method should be used after the first order alignment is complete and within a range of ±2 mm in the x,y directions of the camera.

REFERENCE

1. Information Display Measurements Standard, SID, 2023.
2. R. Beams, A. S. Kim, A. Badano "Transverse chromatic aberrations in virtual reality head-mounted displays" Optics Express 27, 24877-24884 (2019).
3. R. Beams, A. S. Kim, and A. Badano. "Eyebox centering using chromatic aberrations of virtual reality head-mounted displays." Optical Architectures for Displays and Sensing in Augmented, Virtual, and Mixed Reality (AR, VR, MR). Vol. 11310. International Society for Optics and Photonics, 2020.