# User Manual:

# Contrast Measurement Method for Optical See-Through Augmented Reality Head-Mounted Displays

## Tool Reference

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# Instructions on Implementing the Contrast Measurement Method for Optical See-Through Augmented Reality Head-Mounted Displays

## 1. Test Patterns

As illustrated in Fig. 1, checkerboard patterns with a combination of low ("black" box) ($I_L$) and high gray levels ("white" box) ($I_H$) are generated. In general, if the display bit depth is 8-bit, Table A1 provides an example of checkerboard gray level combinations.

If $I_L<L_H$, the checkerboard pattern is used to measure the Michelson contrast $C\{I_L, I_H\}$ as described in Appendix A.4.b. The box dimension should be about 1/10 of the display horizontal and vertical field of view (FOV) to avoid substantial veiling glare and optical aberration that could affect the contrast measurement.

Table A1. Illustration of the checkerboard patterns used to measure the contrast $C\{I_L, I_H\}$ between gray pairs $\{I_L, I_H\}$.

| | | **"White" box gray levels ($I_H$)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **31** | **63** | **95** | **127** | **159** | **191** | **223** | **225** |
| **"Black" box gray levels ($I_L$)** | **0** | | C{0,31} | C{0,63} | C{0,95} | C{0,127} | C{0,159} | C{0,191} | C{0,223} | C{0,255} |
| | **31** | | | C{31,63} | C{31,95} | C{31,127} | C{31,159} | C{31,191} | C{31,223} | C{31,255} |
| | **63** | | | | C{63,95} | C{63,127} | C{63,159} | C{63,191} | C{63,223} | C{63,255} |
| | **95** | | | | | C{95,127} | C{95,159} | C{95,191} | C{95,223} | C{95,255} |
| | **127** | | | | | | C{127,159} | C{127,191} | C{127,223} | C{127,255} |
| | **159** | | | | | | | C{159,191} | C{159,223} | C{159,255} |
| | **191** | | | | | | | | C{191,223} | C{191,255} |
| | **223** | | | | | | | | | C{223,255} |
| | **255** | | | | | | | | | |

## 2. Experimental Setup

This method uses a high-resolution array light measuring device (LMD) with photopic response mounted on a  stage that provides a wide-view spatial luminance measurement. The stage requires at least 3 degree-of-freedom (DoF) translation, and an additional 2-DoF rotation if the eye rotation setup is implemented. Technical requirements on the LMD used for the contrast measurement on HMDs are specified in IEC 63145-20-10 standard [3] and Sec. 19.2 of the Information Display Measurements Standard (IDMS) [4]. The optical axes of the HMD and LMD should be aligned following procedures described in Sec. 19.3 of the IDMS [4] with the entrance pupil location of the LMD placed at the eye point. The LMD should be calibrated such that the digital output is linear to the luminance, for example, using a calibrated imaging photometer.

## 3. Image Acquisition

The measurement takes a wide-view image of the test pattern to measure the luminance and Michelson contrast. The following procedure describes the experimental setup and image acquisition steps.

- Set up the array LMD and align the entrance pupil location of the LMD to the optical axis of the HMD using methods described in Sec. 19.3 of the Information Display Measurement Standard (IDMS) [4].
- In dark condition, render the checkerboard pattern with gray pair {$I_L$, $I_H$} on the HMD with the center of the pattern aligned with the optical axes of the HMD and LMD.
- Adjust the focus of the LMD to the virtual image plane of the test pattern.
- Acquire an image of the test pattern using the LMD.
- Repeat the measurements for all test patterns listed in Table A1.
- Repeat the above steps for each ambient luminance levels ($L_{amb}$) corresponding to the intended use of the device.

## 4. Analysis

a. Michelson contrast in ambient light conditions:

- As illustrated in Figure. 1(a), on a measured checkerboard pattern, define a region of interest (ROI) that contains 4 boxes ($I_{L,1}$, $I_{L,2}$, $I_{H,1}$ and $I_{H,2}$) centered at the location (x, y).
- The contrast of the gray pair {$I_L$, $I_H$} can be computed as

$$C\{I_L, I_H, x, y\} = \frac{\overline{L\{I_H, x, y\}} - \overline{L\{I_L, x, y\}}}{\overline{L\{I_H, x, y\}} + \overline{L\{I_L, x, y\}}},$$

  where $\overline{L\{I_L, x, y\}}$ and $\overline{L\{I_H, x, y\}}$ are the mean luminance measured in the diagonal box pairs {$I_{L,1}$, $I_{L,2}$} and {$I_{H,1}$, $I_{H,2}$} centered at (x, y) [1]. The mean luminance should be measured in each box without including the boundary between the boxes.
- Repeat contrast computation for all (x,y) across the display by shifting the ROI by one box dimension horizontally and vertically.
- For each gray pair {$I_L$, $I_H$}, average the C{$I_L$, $I_H$, x, y} across all locations (x,y) and report the mean contrast of gray combinations C{$I_L$, $I_H$} (see Figure A1(a) as an example).
- Repeat the above steps for Michelson contrast measurement for all ambient light luminance levels and report the contrast values (see Figure A1(b) as an example).

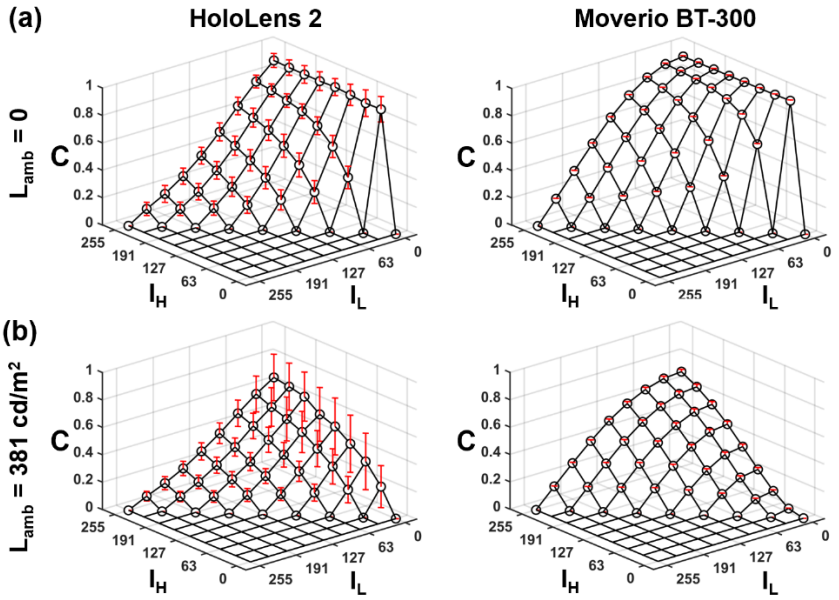


Figure A1. Example of measured contrast of gray combinations {$I_L$, $I_H$} for the HoloLens 2 and Moverio BT-300 AR HMD without ($L_{amb}$ = 0) (a) and with ambient light (e.g., $L_{amb}$ = 381 cd/m$^2$) (b) [1].

b. Contrast uniformity: A spatial distribution of the contrast C{$I_L$, $I_H$} can be obtained from the measurement of C{$I_L$, $I_H$, x, y} at different ambient luminance levels. Figure A2 shows an example of several contrast maps after interpolating the sparse contrast distribution under ambient light.

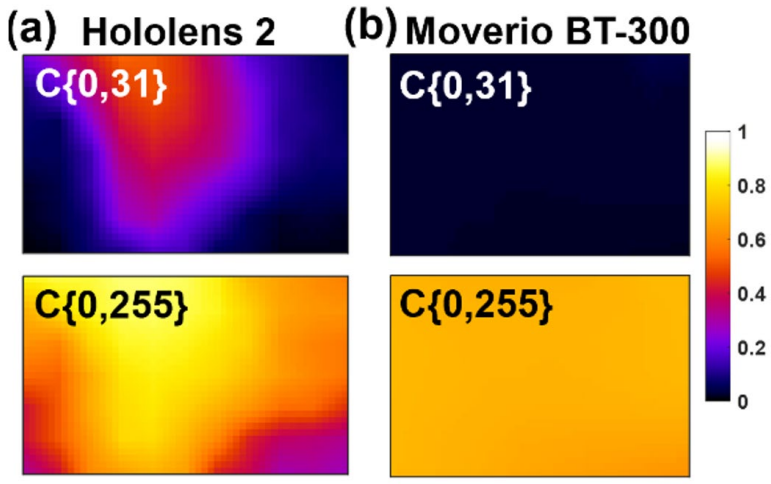


Figure A2. Example contrast maps of the HoloLens 2 (a) and Moverio BT-300 with {$I_L$, $I_H$} of {0, 31} (top) and {0, 255} (bottom) in ambient light field of 381 cd/m$^2$ [1].

**Reference:**

[1] Zhao, Chumin, Ryan Beams, Matthew Johnson, and Aldo Badano. "18-2: Assessment of Image Quality in Augmented Reality Displays Using a Computational Model of Target Detectability." In *SID Symposium Digest of Technical Papers*, vol. 53, no. 1, pp. 194-197. 2022. https://doi.org/10.1002/sdtp.15451

[2] FDA Regulatory Science Tool: "Toolkit for Evaluation of Head Mounted Display Image Quality"

- The WebXR toolkit is provided on GitHub

Reference Standard Documents:

[3] IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Opticalproperties.

[4] Information Display Measurements Standard, SID, 2023.

[5] IEC 63145-20-20:2019 Eyewear display - Part 20-20: Fundamental measurement methods - Image quality.