AR/VR LENS
TESTING NEAR-EYE DISPLAYS WITHIN HEADSETS
TODAY’S TOPICS

• Near-Eye Display Measurement
• The Trouble with Current Methods
• The Solution: AR/VR Lens
  • Replicate the Human Eye
  • Unobstructed FOV
  • High Resolution
  • AR/VR Software Tests
• Application Examples
• Lens Specifications
• Summary
NEAR-EYE DISPLAY MEASUREMENT
CONSIDERATIONS FOR DISPLAYS VIEWED CLOSE-UP
MARKET GROWTH: AR/VR

The AR/VR headset market is expected to reach 81.2 million units by 2021, with a CAGR of 56.1%.

- IDC Research

Source:
WHAT IS THE CONCERN?

• Market trends indicate a need to measure more displays that are:
  • Viewed *extremely close up*
  • Viewed *with a wide field of view* (immersive)
  • Viewed *within head-mounted devices* (goggles and headsets)
COMMON APPLICATIONS

- Virtual Reality (VR)
- Augmented Reality (AR)
- Mixed Reality (MR)
Near-Eye Displays

- Projections are magnified for wider, immersive field of view (FOV), but cause more noticeable defects
  - Uniformity issues, dead pixels, line defects, inconsistency from eye to eye
- More pixels per eye increases realism, but require higher-res measurement device
With display in fixed position, horizontal FOV leveraged for immersion, but requires wide FOV optics for complete evaluation

- Display testing from position of the human eye while capturing full horizontal angular FOV

- Some AR/VR devices replicate human binocular FOV (approx. 120 degrees), requiring equivalent measurement FOV
SAMPLE HEADSET FOVS

Source: http://vrheadsets.com/field-of-view
DISPLAYS IN **HEAD-MOUNTED DEVICES**

- Measuring what the user sees means getting inside the headset
  - Need a more compact optical system
  - Need to position a measurement device at the designed location of the human eye in the headset to capture the same FOV intended to be viewed by the user through the headset lenses
UNIQUE MEASUREMENT CRITERIA

Potential AR/VR Display Tests:

- Luminance and color uniformity
- Image clarity (Slant Edge Contrast or MTF)
- Image distortion
- Focus uniformity
- Field of view measurements
THE TROUBLE WITH CURRENT METHODS
EXISTING SOLUTION OPTIONS

Display measurement performed by:

1. **Machine Vision Cameras:** Not appropriate for absolute luminance & color measurement.

2. **Limited Resolution:** Low-resolution sensors, <16 megapixels.

3. **Standard Optics:** E.g., traditional 35mm lens options with internal aperture.

4. **Custom Optics:** Not productized; expensive and long lead time.

5. **Made-in-House Test Software:** Limited capability, support, and scalability.
MACHINE VISION CAMERAS

- Not appropriate for absolute luminance and color measurement:
  - **No luminance & Cx,Cy coordinates**
    - Unlike imaging colorimeters, do not offer CIE-matched color filters for accurate luminance and chromaticity values.
  - **Not calibrated**
    - Unlike Radiant systems, do not feature advanced factory calibrations for color, luminance, linearity, and image correction for highest accuracy.
  - **Low Signal-to-Noise Ratio (SNR)**
    - Unlike Radiant systems, are not optimized for the lowest noise possible with electronics design and thermoelectrically-cooled sensors to increase dynamic range and ensure repeatability of measurements.
LIMITED RESOLUTION

• Low-Resolution Sensors:
  • Inadequate for pixel-dense displays
  • May miss dot, particle, pixel, and other small defects
  • Incapable of MTF measurement
STANDARD OPTICS

• Regardless of the imaging system:
  • **Size** of standard optical hardware prevents positioning measurement system within headset
  • **Aperture** of standard optics causes occlusion of the image through goggles
OBSTRUCTED FIELD OF VIEW

Standard Lens
Aperture inside lens; occlusion from AR/VR device hardware
CUSTOM OPTICS

- Customizing a lens solution means:
  - Increased expense
  - Long lead time
  - Minimal scalability to future applications
  - Minimal product support through project lifecycle
MADE-IN-HOUSE TEST SOFTWARE

• In-house software means:
  • Increased expense
  • Increased time to implement
  • Minimal scalability to future applications
  • Limited extendibility to other display test applications
  • Minimal product support
THE SOLUTION: AR/VR LENS
FOR NEAR-EYE DISPLAY TESTING WITHIN HEADSETS
THE AR/VR LENS

Measure near-eye displays (NED) in AR/VR goggles and headsets
AR/VR LENS

Unique Features

• Aperture (entrance pupil) located on front of lens
• 3.6 mm aperture
• Designed to be positioned in eye relief location
• Wide field of view (FOV): 120° horizontal
  • Accommodates most AR/VR headsets
  • Distortion corrected automatically for accurate testing
• Full suite of TrueTest™ display tests
## All Near-Eye Display Types

<table>
<thead>
<tr>
<th>Experience</th>
<th>Projection</th>
<th>View Channel</th>
<th>Display Type</th>
<th>Optical Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immersive</td>
<td>Reflective</td>
<td>Monocular</td>
<td>LCD</td>
<td>Opaque</td>
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<tr>
<td>See-through</td>
<td>Transmissive</td>
<td>Binocular</td>
<td>LCOS</td>
<td>Bird Bath</td>
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<tr>
<td></td>
<td>Transflective</td>
<td>Bi-Ocular</td>
<td>OLED</td>
<td>Free Space</td>
</tr>
<tr>
<td></td>
<td>Emissive</td>
<td></td>
<td>DLP</td>
<td>Light guide</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Laser MEMs</td>
<td>Waveguide</td>
</tr>
</tbody>
</table>

**Virtual Reality (VR)**

- Immersive
- See-through

**Augmented Reality (AR)**

- Reflective
- Transmissive
- Transflective
- Emissive

**Mixed Reality (MR)**

- Monocular
- Binocular
- Bi-Ocular

See the Difference
REPLICATE THE HUMAN EYE

- Aperture (entrance pupil) size 3.6 mm receives equivalent light (captures equivalent detail) as the human eye
  - Simulates human eye pupil size
- Aperture located on front of lens enables visibility to full display FOV
  - Simulates position of human eye in headset
    - Typical lenses have aperture inside of lens. For near-eye applications, this distance results in occlusion of the image and prevents the full display FOV from being captured
- Aperture position and lens FOV combine to capture full 120° horizontal FOV
  - Covers approximate FOV of binocular human vision
IMPORTANCE OF APERTURE POSITION

• Aperture at the front of the lens simulates the human eye position within the headset
  • In standard lenses, aperture is inside lens. Lens hardware puts distance between entrance pupil and designed human eye position
  • Distance causes occlusion of the display by the headset hardware
  • At the eye position, the aperture can capture the full FOV without occlusion
UNOBSTRUCTED FIELD OF VIEW

Standard Lens

Aperture inside lens; occlusion from AR/VR device hardware
UNOBSSTRUCTED FIELD OF VIEW

AR/VR Lens
Aperture at front of lens; no occlusion

AR/VR device entrance aperture

θ

CAMERA APERTURE

CCD
HIGH RESOLUTION

• Pair lens with Radiant ProMetric® 16-, 29-, and 43-megapixel imagers
  • **Precision:** Detect pixel- and subpixel-level defects
  • **Efficiency:** Detect all meaningful variations across pixel-dense displays in a single image
TrueTest™ SOFTWARE

- Full suite of display tests:
  - Luminance
  - Chromaticity
  - Uniformity
  - Contrast
  - Mura (blemishes)
  - Pixel/line defects
- TT-ARVR Software Module
TT-ARVR SOFTWARE TESTS

• TrueTest TT-ARVR software module includes a suite of unique tests for AR/VR applications:
  • **Slant Edge Contrast**
    • *Measure MTF to evaluate image clarity. Based on ISO 12233.*
  • **Image Distortion**
    • *Characterize distortion from headset.*
  • **Field View**
    • *Report horizontal, vertical, and diagonal AR/VR device FOV.*
  • **Spatial x,y positions given in degrees (°)**
    • *Locate POI on-screen in terms of angular FOV.*
APPLICATION EXAMPLES
TT-ARVR SOFTWARE MODULE IMAGES AND ANALYSIS
<table>
<thead>
<tr>
<th>Test</th>
<th>Color?</th>
<th>Pattern(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field View</td>
<td>Photopic</td>
<td>White 255, or Green</td>
</tr>
<tr>
<td>Uniformity</td>
<td>Color</td>
<td>White 255</td>
</tr>
<tr>
<td>ANSI Color Uniformity</td>
<td>Color</td>
<td>White 255, Red, Green, Blue</td>
</tr>
<tr>
<td>Sequential Contrast</td>
<td>Photopic</td>
<td>Black, White (selected in test)</td>
</tr>
<tr>
<td>Distortion</td>
<td>Photopic</td>
<td>9 Dot Distortion Pattern (Red, Green, Blue)</td>
</tr>
<tr>
<td>MTF Slant Edge</td>
<td>Photopic</td>
<td>4 Square Pattern (White)</td>
</tr>
<tr>
<td>Checkerboard Contrast</td>
<td>Photopic</td>
<td>11x11 Checkerboard (White)</td>
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</table>
SEQUENCE: ARVR_DEMO.SEQX

<table>
<thead>
<tr>
<th>Select</th>
<th>Measurement Setup</th>
<th>Analysis</th>
<th>Edit</th>
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<tbody>
<tr>
<td>1</td>
<td>Green</td>
<td>Field View</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>White</td>
<td>Uniformity</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>White</td>
<td>ANSI Brightness</td>
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<tr>
<td>4</td>
<td>White</td>
<td>ANSI Color Uniformity</td>
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</tr>
<tr>
<td>5</td>
<td>Black</td>
<td>Sequential Contrast</td>
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<tr>
<td>6</td>
<td>Red</td>
<td>ANSI Color Uniformity</td>
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</tr>
<tr>
<td>7</td>
<td>Green</td>
<td>ANSI Color Uniformity</td>
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</tr>
<tr>
<td>8</td>
<td>Blue</td>
<td>ANSI Color Uniformity</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Red - Distortion</td>
<td>Distortion</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Green - Distortion</td>
<td>Distortion</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Blue - Distortion</td>
<td>Distortion</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>White - MTF</td>
<td>MTF_SlanEdge</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>White - Checkerboard</td>
<td>CheckerboardContrast</td>
<td></td>
</tr>
</tbody>
</table>
FIELD VIEW

Reports out the horizontal, vertical and diagonal Field of View of the AR/VR headset. Results reported in degrees.
UNIFORMITY

Creates NxN grid on image, and reports out average luminance of each grid point, as well as additional statistics (min, max, difference, etc.)
ANSI COLOR UNIFORMITY

13 ANSI points placed on measurement, per ANSI standard. Report out color coordinates at each point, and max color difference. Pass/Fail available.

4 patterns measured (White, R, G, B)
SEQUENTIAL CONTRAST

Takes measurement of Black, and White patterns. Compares luminance values in POI at center of image. Computes contrast ratio

<table>
<thead>
<tr>
<th>Analysis Name</th>
<th>Pattern Name</th>
<th>Serial</th>
<th>Result</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 Sequential Contrast</td>
<td>Black</td>
<td>4</td>
<td>AvgLv1</td>
<td>0.178</td>
<td>cd/m²</td>
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<tr>
<td>36 Sequential Contrast</td>
<td>Black</td>
<td>4</td>
<td>AvgLv2</td>
<td>130.227</td>
<td>cd/m²</td>
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<tr>
<td>37 Sequential Contrast</td>
<td>Black</td>
<td>4</td>
<td>ContrastRatio</td>
<td>731.6</td>
<td>Contrast Ratio</td>
</tr>
</tbody>
</table>
Distortion test measures several geometric distortion parameters to determine if the image is off-center, rotated, keystoned, or pin-cushioned/barrel distorted. A pattern consisting of 9 dots (on a 3x3 grid) is displayed and measured. The program finds the center location of the nine dots and then performs measurements between dots to determine if the tests pass or fail.
MTF SLANT EDGE

Analysis Results

<table>
<thead>
<tr>
<th>Analysis Name</th>
<th>Pattern Name</th>
<th>Serial</th>
<th>Result</th>
<th>Value</th>
<th>Unit</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(1)_DirLeft_MTF_Gfreq10</td>
<td>0.0332</td>
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<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(1)_DirLeft_MTF_Gfreq15</td>
<td>0.0089</td>
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<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(1)_DirLeft_MTF_Gfreq20</td>
<td>0.0056</td>
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</tr>
<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(1)_DirLeft_MTF_GMTF20%</td>
<td>2.6312</td>
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<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(1)_DirLeft_Freq_GMTF10%</td>
<td>3.06</td>
<td></td>
<td></td>
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<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(2)_DirLeft_MTF_Gfreq5</td>
<td>0.0622</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(2)_DirLeft_MTF_Gfreq10</td>
<td>0.0578</td>
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</tr>
<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(2)_DirLeft_MTF_Gfreq15</td>
<td>0.0058</td>
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<td></td>
</tr>
<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(2)_DirLeft_MTF_Gfreq20</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTF_SlantEdge</td>
<td>White - MTF</td>
<td>4</td>
<td>POI(2)_DirLeft_Freq_GMTF20%</td>
<td>3.0769</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHECKERBOARD CONTRAST

Analysis Results

<table>
<thead>
<tr>
<th>Analysis Name</th>
<th>Pattern Name</th>
<th>Serial</th>
<th>Result</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CheckerboardContrast-ARVR</td>
<td>White - Checkerboard</td>
<td>4</td>
<td>AvgLv1</td>
<td>127.581</td>
<td>cd/m²</td>
</tr>
<tr>
<td>CheckerboardContrast-ARVR</td>
<td>White - Checkerboard</td>
<td>4</td>
<td>LvVValues</td>
<td>143.8, 162.1, 149.8, 151.4, 163.6, 124.5, 148.6, 149.5, 144.5, 151.2, 163.4, 137.5, 152.1, 141.5, 143.1, 155.8, 143.8, 137.143...</td>
<td>cd/m²</td>
</tr>
<tr>
<td>CheckerboardContrast-ARVR</td>
<td>White - Checkerboard</td>
<td>4</td>
<td>AvgLv2</td>
<td>4.009</td>
<td>cd/m²</td>
</tr>
<tr>
<td>CheckerboardContrast-ARVR</td>
<td>White - Checkerboard</td>
<td>4</td>
<td>Lv2Values</td>
<td>1.8, 2.1, 3.3, 3.8, 12.2, 1.9, 6.4, 4.8, 4.2, 7, 17.0, 3.3, 3.2, 5, 2.4, 2.6, 4, 4.4, 4.6, 2.6, 3.2, 5.4, 2.3, 3.2, 3.1, 1.9, 5.8, 3.3, 2.8, 2...</td>
<td>cd/m²</td>
</tr>
<tr>
<td>CheckerboardContrast-ARVR</td>
<td>White - Checkerboard</td>
<td>4</td>
<td>ContrastRatio</td>
<td>31.285493874431</td>
<td>CFR</td>
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</table>
LENS SPECIFICATIONS
## AR/VR Lens Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>AR/VR Lens</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Application</strong></td>
<td>Light and color measurement for near-eye displays (NED) in headsets</td>
</tr>
<tr>
<td><strong>Aperture</strong></td>
<td>3.6 mm; Located at front of lens</td>
</tr>
<tr>
<td><strong>Focus</strong></td>
<td>Manual; Range 0.25 m to infinity</td>
</tr>
<tr>
<td><strong>Measurement Capabilities</strong></td>
<td>Luminance, Radiance, CIE Chromaticity Coordinates, Correlated Color Temperature (CCT)</td>
</tr>
<tr>
<td><strong>Units</strong></td>
<td>cd/m², nit, W/sr/m², foot-lambert, CIE (x, y) and (u’, v’), Kelvin (CCT)</td>
</tr>
<tr>
<td><strong>Paired with Camera</strong></td>
<td>I2/Y2, I8, I16/Y16, I29/Y29, Y43</td>
</tr>
<tr>
<td><strong>Approx. FOV (Horizontal)</strong></td>
<td>30°, 60°, 90°, 120°</td>
</tr>
<tr>
<td><strong>Approx. FOV (Vertical)</strong></td>
<td>22°, 45°, 60°, 80°</td>
</tr>
</tbody>
</table>
AR/VR LENS DIMENSIONS
AR/VR DISPLAY TEST SOLUTION

AR/VR Lens

ProMetric® Imaging Colorimeter or Photometer (29- or 43-megapixel recommended)

TrueTest Software (TT-ARVR module optional)
FACTORY DISTORTION CALIBRATION

Before distortion calibration

After distortion calibration

*Comes with factory Four-Color Calibration only; not designed to be NIST traceable.*
SUMMARY

✓ Growth in embedded and AR/VR markets requires testing new displays viewed close-up, from a fixed position, within headset hardware.

✓ Standard display measurement equipment lacks the optical specifications to capture displays within headsets to evaluate the full display FOV.

✓ Radiant’s AR/VR Lens is the only solution with unique optical components that replicate the human pupil size (3.6 mm) and position within AR/VR goggles and headsets to capture the full display FOV to 120 degrees.
Working closely with world class brands and manufacturers to deliver **creative visual inspection solutions** that improve quality, reduce costs, and increase customer satisfaction.
THANK YOU!

Questions? Contact: Info@RadiantVS.com