RADIANT
VISION SYSTEMS

Medical AR/VR: *Addressing Hardware & Software Quality Testing Challenges*

Presented By Danton Bennett | February 10, 2026

Agenda

RADIANT VISION SYSTEMS

- XR (AR/VR/MR) in Medicine and Healthcare
- XR System Visual Quality
- AR/VR Regulatory Environment
- XR System Testing Requirements & Challenges
- Solutions for Medical XR System Testing
- Summary

Presenter /

Danton Bennett | Regional Sales Manager

Danton Bennett is a Sales Engineer at Radiant Vision Systems with just under five years of experience in display and lighting measurement solutions. He began his career as an Applications Engineer, where he partnered closely with customers to support proof-of-concept projects, deliver technical training, and develop customized inspection solutions. In his current role on the sales team, Danton leverages his strong technical background to help customers identify the right imaging and measurement technologies to improve product quality and manufacturing efficiency.

RADIANT

Light & Color

Automated Visual Inspection

Global Support

XR Use in Medicine and Healthcare

Applications and Considerations

Key Applications

Education

- Anatomy
- Skills training
- Simulated procedures
- Patient interface simulation

Surgery & Treatment

- Surgical prep/practice
- In surgery
- Robotic surgery
- Operative and post-operative services

Rehabilitation

- Rehabilitation
- Physical therapy

Pain Management

- During treatments
- Chronic pain

Mental Health

- PTSD
- Anxiety
- Phobias

Using XR in Medicine

CAPABILITIES

- Data visualization
- Integrating data with sensor and camera input
- Interactivity

DELIVERY

- Hardware
- Software
- Content
- Services

USER EXPERIENCE

Virtual Reality

- Immersive
- Interactive

Augmented Reality

- Enhanced background environment

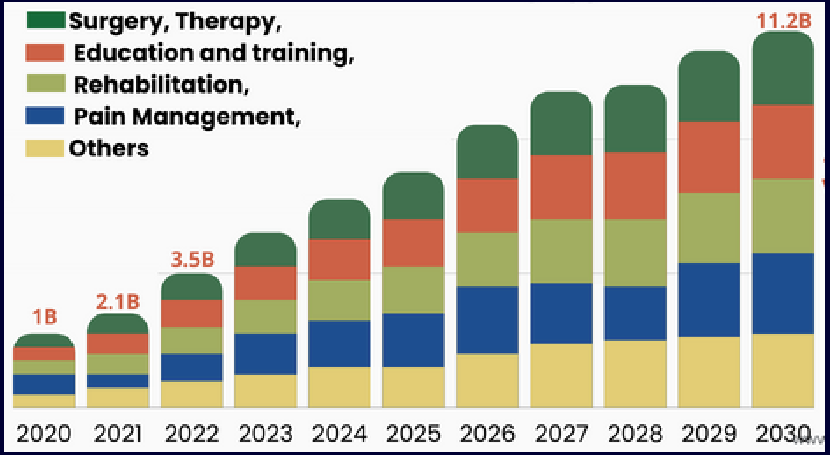
Mixed/Merged Reality

- Integration with background environment
- Interactive

Emergence of Medical XR

- Global Market: USD 2.93 Billion in 2022, growing 32.33% CAGR to USD 11.92 B by 2027*
- US market currently largest, Asia/Europe following in the coming years
- AR/MR segment = 56.9% of market revenues*

AR/VR Revenues by Application (USD Billion)**



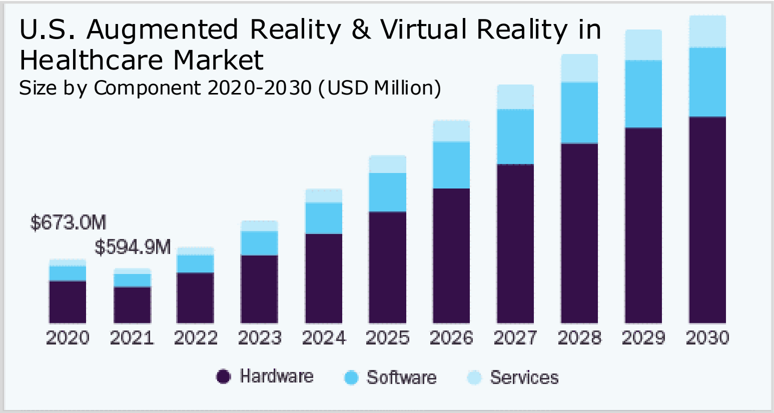
*SOURCE: Market Data Forecast
**IMAGE SOURCE: Custom Market Insights

Medical XR Driving Factors

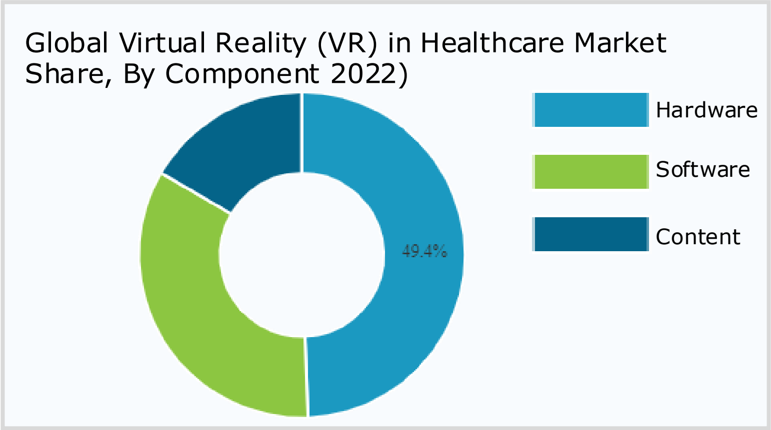
- COVID increase in no-touch training and treatment methods, virtual visits
- Effectiveness of VR treatment for a significant number of mental health issues such as anxiety and PTSD
- Efforts to reduce the complexity of medical procedures, increase use of non-invasive procedures
- Increased private investment in healthcare and emerging tech

Medical AR/VR Segments

- Hardware revenue share: 67.5%*
- Software segment growing faster than hardware, increasing market revenue share by 2030
- Current VR market:
  - Hardware 49.4% of revenues
  - Software & Content: 50.6%



SOURCE: Grandview Research



SOURCE: Fortune Business Insights

Medical AR/VR Segments

- XR Devices
  - ➢ *Head-mounted displays*
  - ➢ *Smart glasses*
  - ➢ *3D sensors*
- Cross-Market Devices
- Specialty/Integrated Systems

Market Device Examples

Microsoft HoloLens

Meta Quest

Magic Leap

Apple Vision Pro

HTC Vive Flow

Specialty System Example

Augmedics
AR Spinal Surgery system,
Received FDA 510(k)
clearance Dec. 2019

Device Design Considerations

Minimize discomfort, e.g.,

- Weight and size
- Customizable fit
- Visual fatigue

Optical components, e.g.,

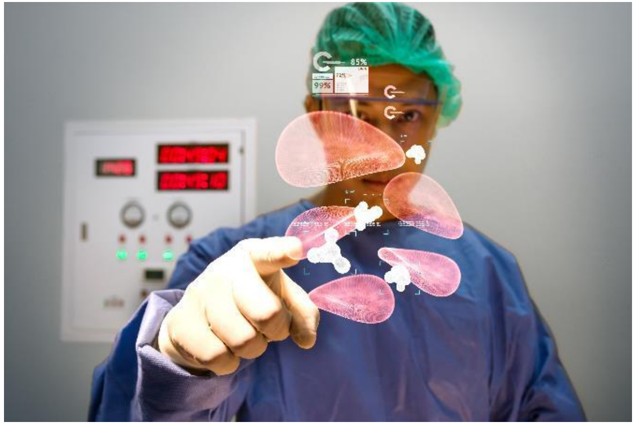
- Combiner
- Waveguides (reflective, polarized, diffractive, holographic)
- Lightguides
- Lenses
- Prisms and mirrors
- Gratings and metasurfaces

Display technology, e.g.,

- Projection – laser
- Projection - LED / LCOS
- OLED / MicroLED / MicroOLED

Sensor/camera integration

Software Development Considerations



- Device platform
- Tech stack
  - Development platform (e.g., Snapdragon)
  - Programming language
  - SDK
  - Database
- UI and UX design
- Marker recognition
- Integration
  - Camera & sensor input
  - GPS
  - Third-party apps
  - Image libraries
- Data accuracy and security

**Use of single hardware device by multiple software applications increasingly common*

AR/VR Regulatory Environment

Current and emerging standards

XR System Visual Quality

Visual quality requirements and performance challenges

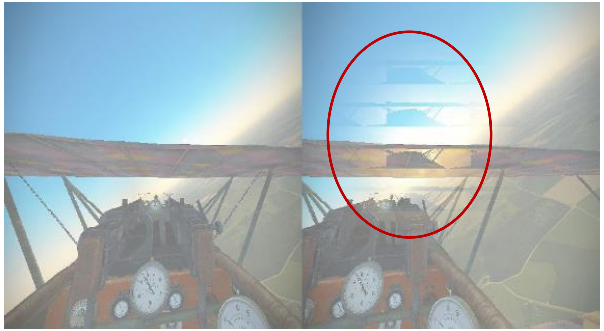
Baseline XR Requirements

- Requires hardware and software that are each unique to AR/VR and highly complex.
- Hardware and software must work together seamlessly to provide a controllable and consistent experience
- Ensure safe and comfortable user experience
- Meet visual quality standards:
    - *Clarity*
    - *Consistency*
    - *Uniformity*
    - *Accuracy*

Medical XR Requirement:
Suitable for use by clinicians and patients in medical and treatment settings

Visual Quality Issues

- Blurring
- Distortion
- Diffraction effects
  - Color separation
- Dimming
- Ghosting / double images
- Color non-uniformity
- Brightness non-uniformity
- Defects
  - E.g., pixel defects, lines
- Poor contrast
- Dual eye consistency



Optical Quality Inspection Parameters

VIRTUAL REALITY

- Image resolution: clarity/sharpness
- Brightness (luminance) uniformity
- Color (chromaticity) uniformity
- Field of view
- Focus/foveated rendering
- Defects and artifacts
    - E.g., dead pixels

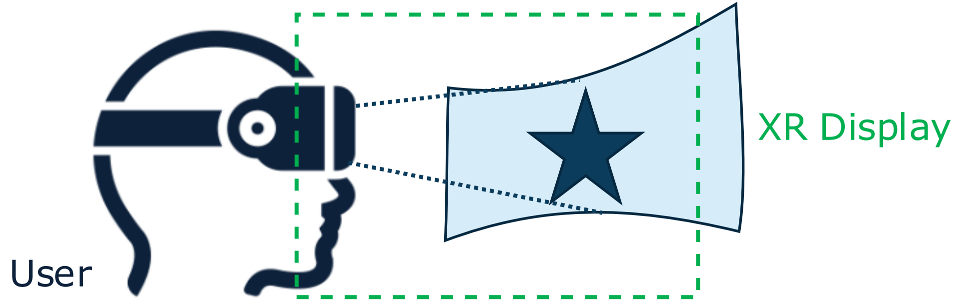
AUGMENTED/MIXED REALITY

- Image resolution: clarity/sharpness
- Brightness/contrast against background environment
- Field of view
- Defects and artifacts
    - E.g., ghosting
- Contrast vs. background environment

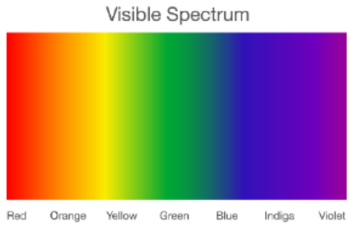
XR System Testing Requirements and Challenges

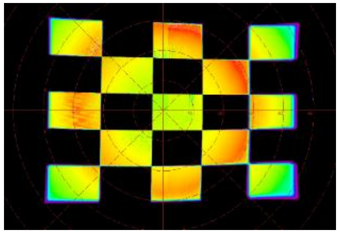
Unique testing requirements for near-to-eye (NED) devices

XR Displays & User Perception



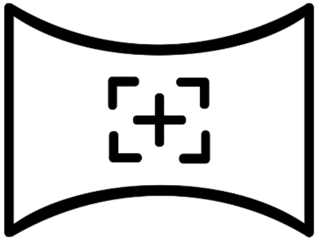
Emulate user's visual perception of:

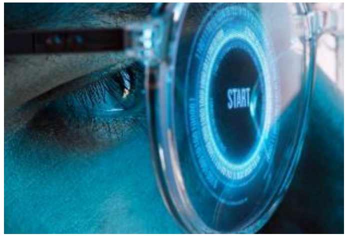




Visible Light | Spatial Images

Within the context of:





Angular FOV | Near-Eye Position

XR Displays & User Perception

Testing Considerations:

- Photometer (monochrome/luminance)
- Colorimeter (chromaticity)
- Dark lab environment
- Ambient light environment
- Single eye measurement
- Dual eye measurement

Essential Components:

Camera/Imaging System

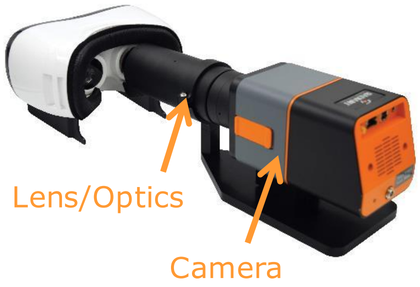
+

Lenses

+

Software

Images captured → **Software generates test patterns displayed on DUT** → **Software outputs data and analysis reports**



Human Vision Characteristics

1 Perception of light and color

2 Size of human pupil

3 Pupil location / position

4 Human FOV

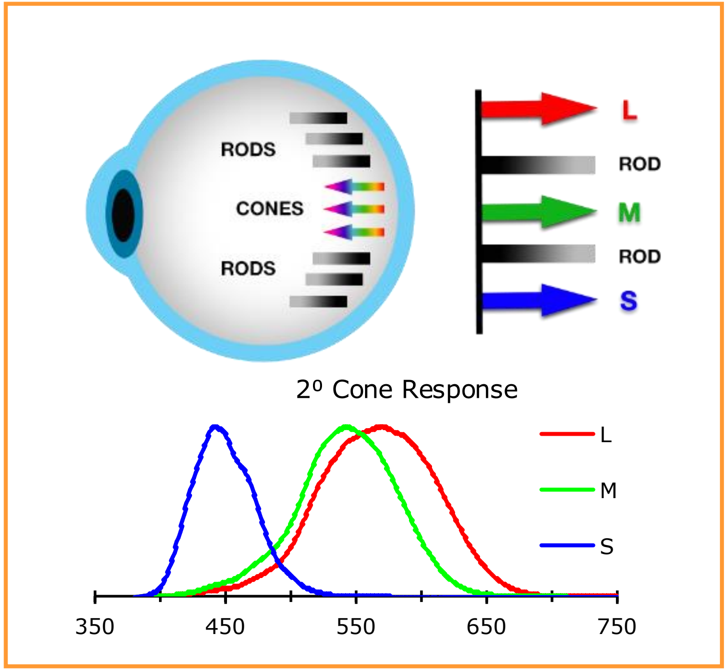
5 Human visual acuity (resolution)

6 Human foveal area (focus)

7 Binocular vision and interpupillary distance

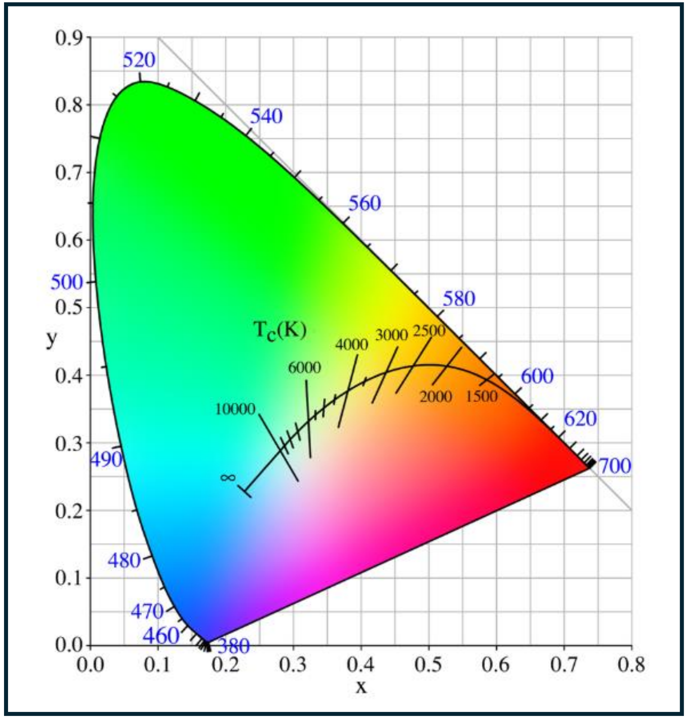
Requirement: Perception of Color & Light

The human eye is sensitive to color and brightness



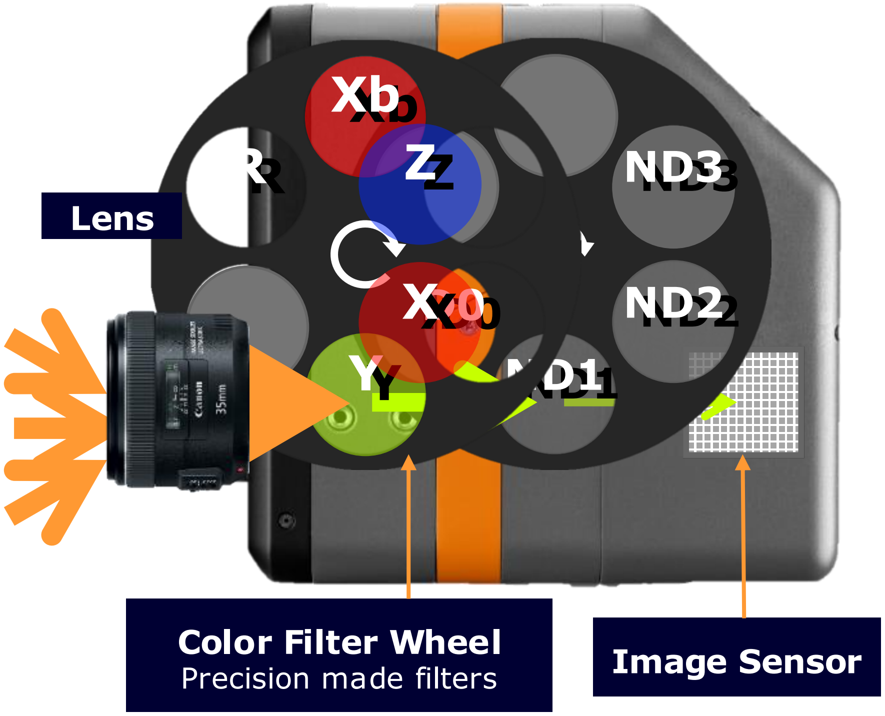
CIE Color Chart (C_x, C_y)

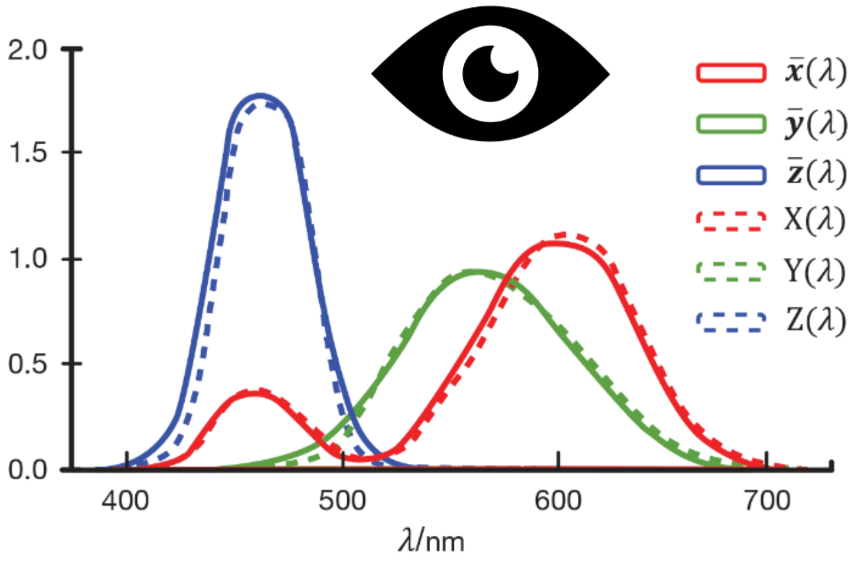
CIE Color Space: Total visible colors (to the human eye)



Recommended: Photometry & Colorimetry

ProMetric® Imaging Colorimeter

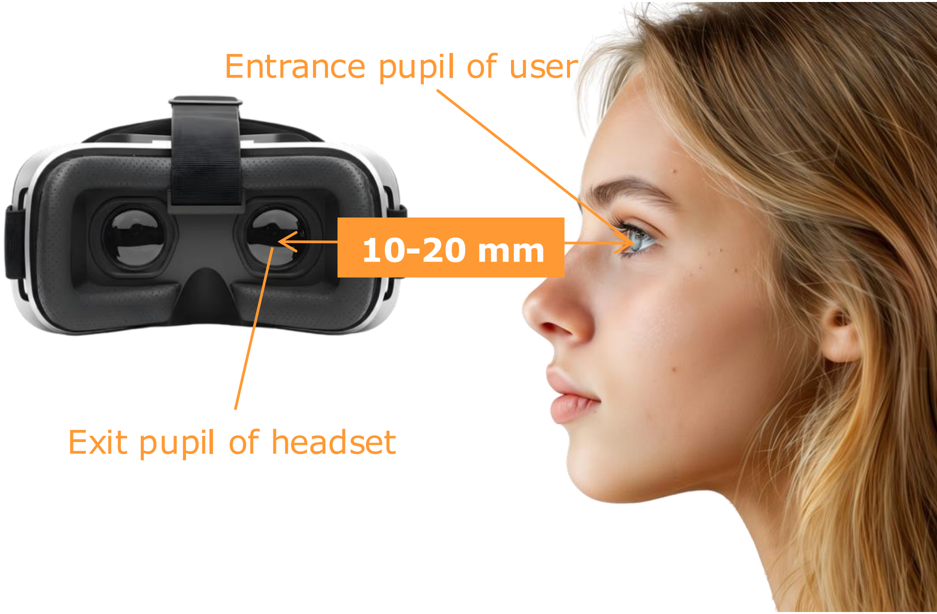




Requirement:
Match Entrance Pupil

- Intended entrance pupil position (position of the human pupil) relative to the location of the exit pupil of the headset (headset eyepiece)

- Pupil **size** (aperture)
  - Average human pupil (2-8 mm diameter)



Challenge: Headgear

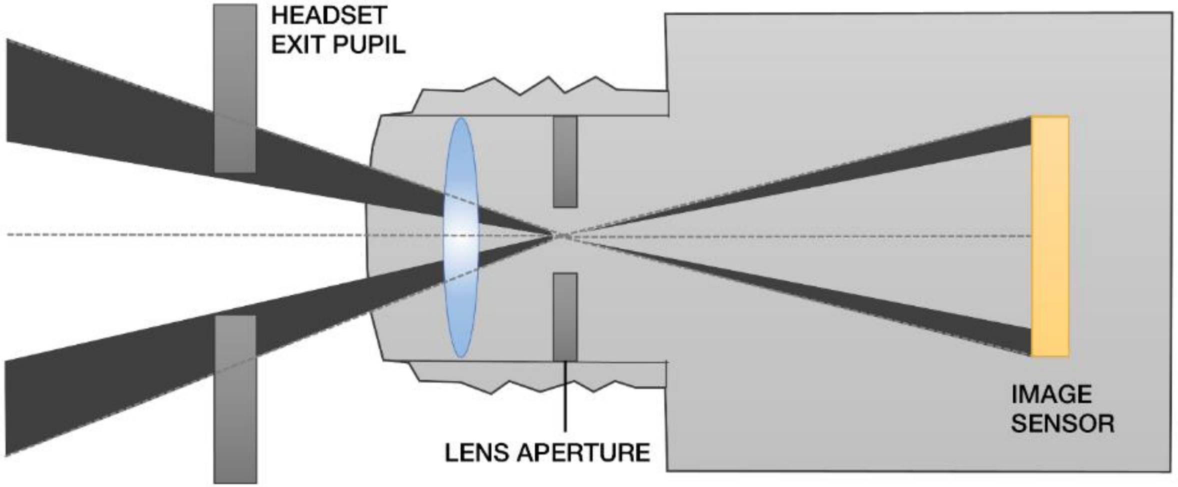
How can the entrance pupil position be achieved here?

Examples of current XR device headgear, which may impede measurement using standard optics.

(From left to right: Oculus Quest 2; Varjo VR-3; HoloLens 2; Vuzix Blade Upgraded Smart Glasses.) (Right: Varjo VR-3)

Challenge: Lens Geometry

- Buried entrance pupil (aperture) of the imaging system results in "knothole effect"

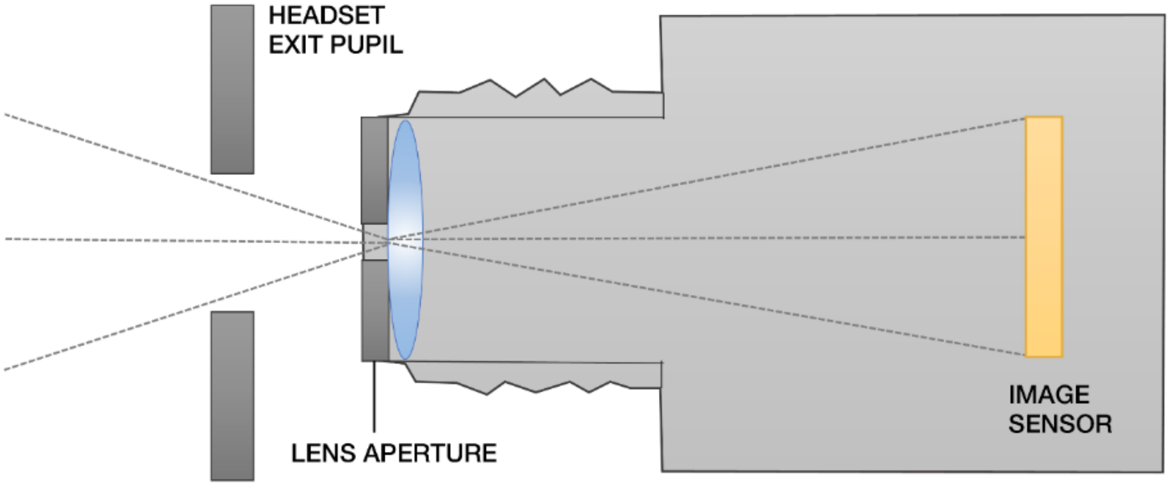


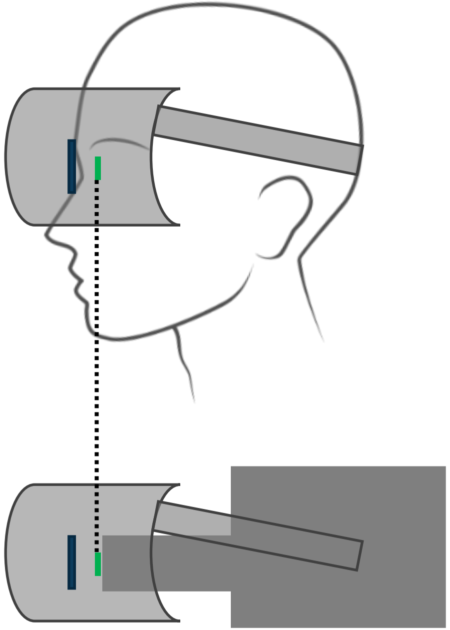
Far from knothole – FOV is clipped

Close to knothole – wider FOV can be seen

Recommended: Specialized Lens Design

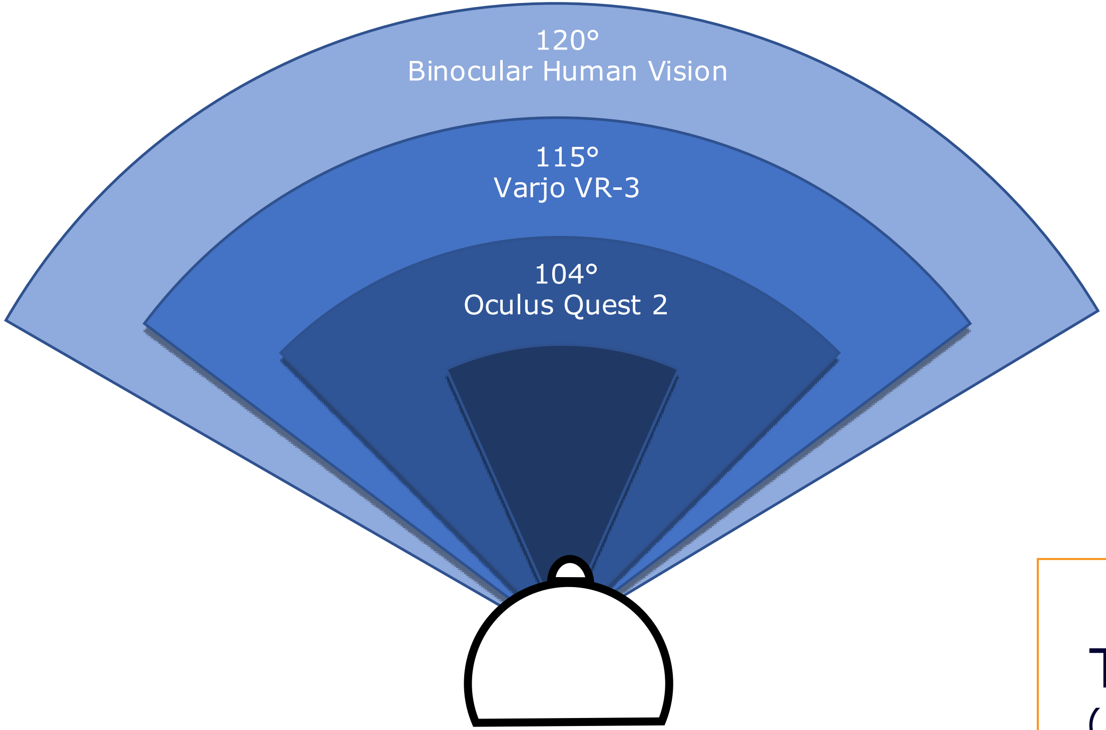
- Aperture at front of imaging lens enables **positioning** at intended entrance pupil position
- Aperture **sized** like average human pupil





Entrance pupil position matched

Requirement: Match Angular Field of View



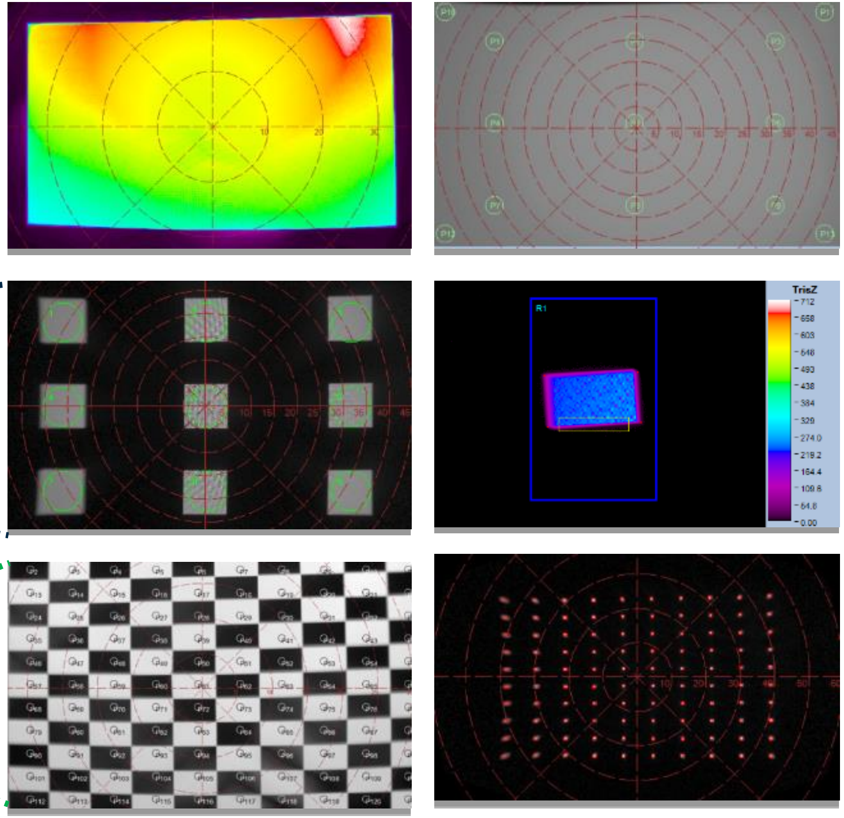
- Capture virtual elements (and their constituent light & color values) in their true angular positions
- Capture potentially wide FOVs in a single image
- Emulate human FOV of immersive display

Recommended:
Test System Lens FOV
(+/- 23°, +/- 35°, +/- 60°, etc.)

Recommended: Imaging

- Visualize XR display (projected elements) in spatial context
- Capture full FOV of the display at once

ProMetric® Imaging Colorimeter and Photometer



LumiTop 4000/5300 W/ Two ARVR lens Options

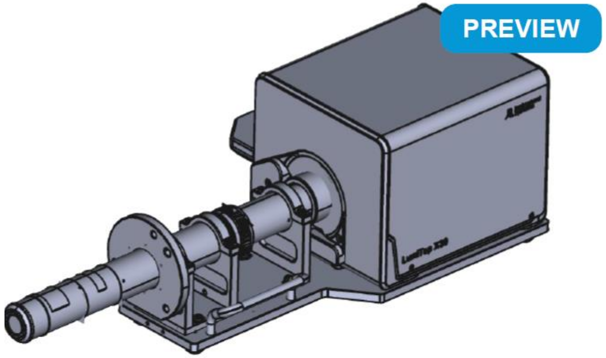
	LumiTop 4000	LumiTop 5300
Sensor Res.	12MP	24MP
Res. [Pixel/°]	33	42
FOV [°]	120 x 85	120 x 105
Hardware trigger	yes	yes
Lens type	Periscope or Straight	
Pupil	2.0-3.6mm (exchangeable)	
Multiple VIDs [m]	0.5 – infinity (e.g. 0.5, 1.0, 1.5)	
Software	LumiSuite SDK AR/VR GUI tool for LS SDK + beta features	
Coordinate systems	Cartesian & Polar	

LumiTop X30 W/ AR Lens:

LumiTop X30 with AR Lens: Preliminary Specs

PREVIEW

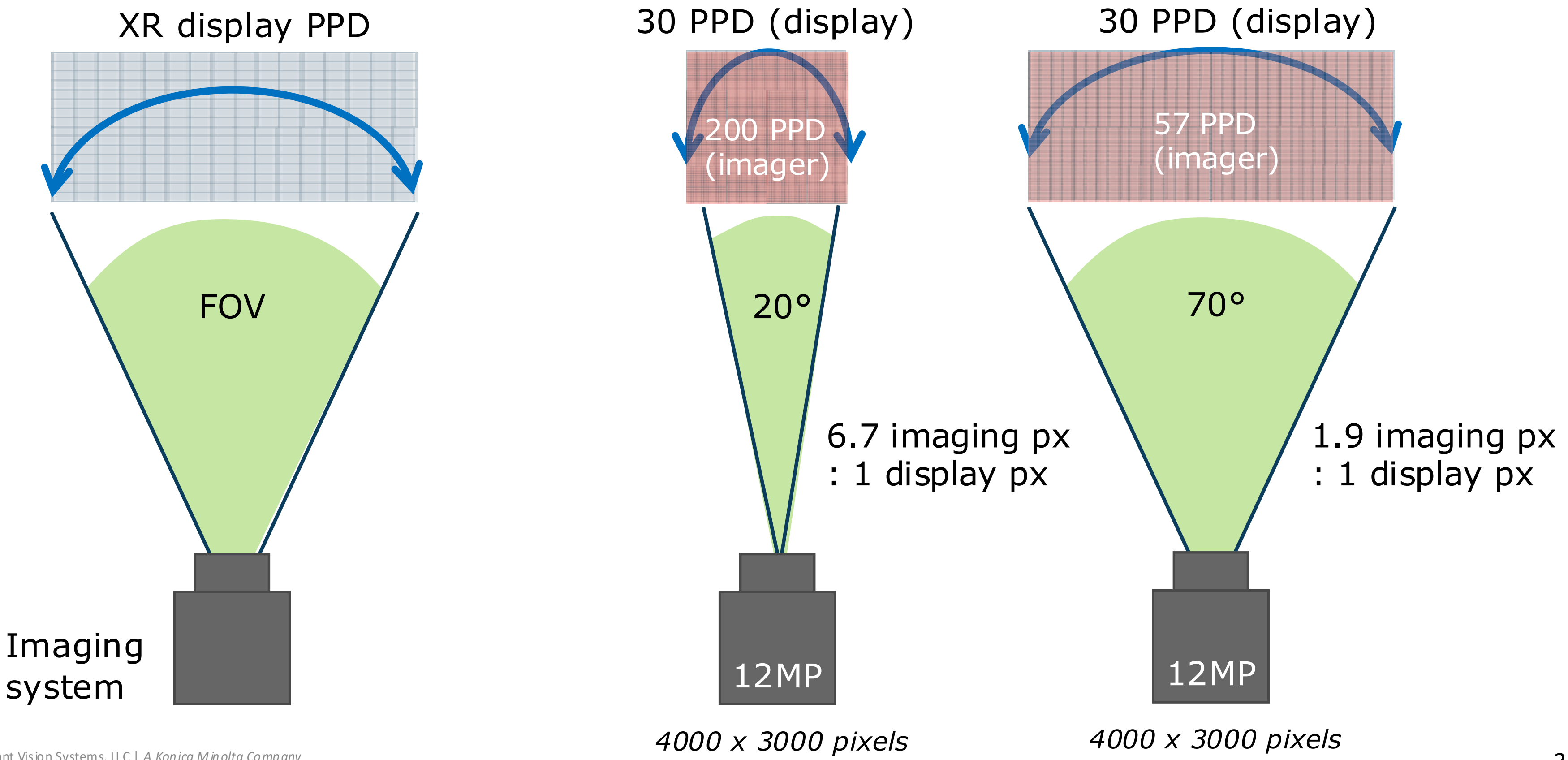
Parameter	
Measurement quantities	**2D:** Luminance, color, uniformity, distortion, MTF, contrast, chromatic aberration **Spot:** Spectrum, luminance, color, flicker
Camera	6464 x 4852 px (31 megapixels, RGB, CMOS)
Entrance pupil diameter	1 - 5 mm
Focus distance	0.25 m to infinity
Field of view (H x V)	42° x 32° (±21° x ±16°)
Resolution	150 pixel/degree
Lens barrel diameter (from lens front surface to flange (distance 195 mm))	46 mm



Note: First prototype expected 2026

Challenge: Display FOV & PPD

Requirement: Pixels Per Degree (PPD)



Challenge: Display Resolution

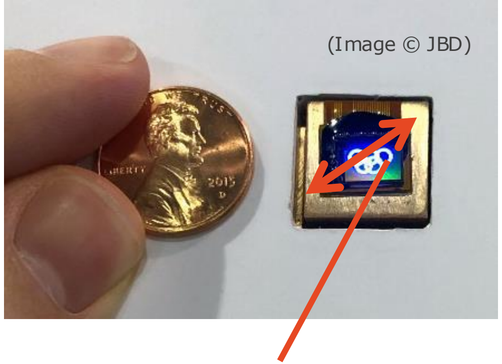
How can we measure ultra-high-resolution displays?

Omnivision OPO2220 LCoS microdisplay with integrated AR/VR driver, 1920 x 1080 pixels

0.39” (9.9 mm) diagonal

AMOLED AR/VR display and driver, 1280 x 960, 5644 PPI

MicroLED AR/VR micro-display from Jade Bird Display, 2560 x 1440, 10000 PPI



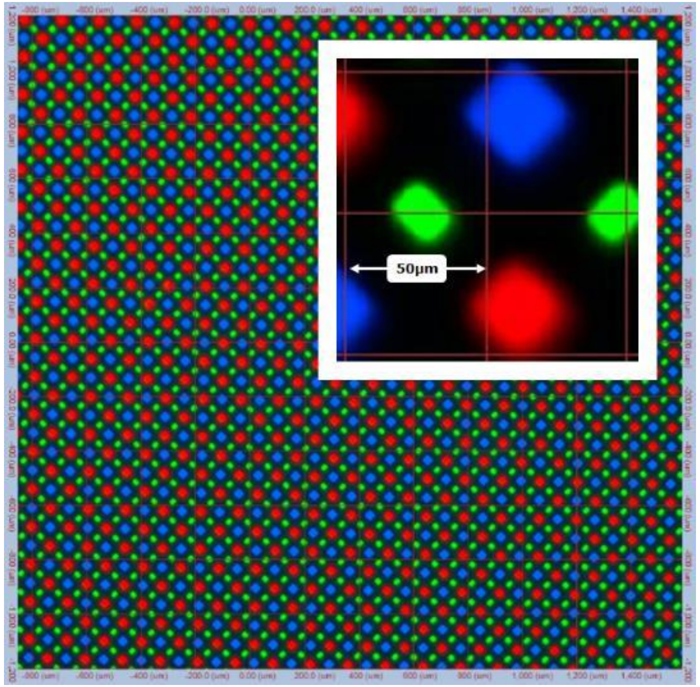
0.31” (7.87 mm) diagonal

Recommended: High-resolution Imager

Advantages:

- More sensor pixels per display pixel—across any FOV
- Accurate measurement of high-resolution, pixel-dense displays such as XR, microdisplays
- Ability to discern individual subpixels to correct uniformity of emissive displays (OLED, microLED, microOLED, etc.)
- Efficient single-image capture for production testing

**Other specs to look for: high dynamic range, repeatability*

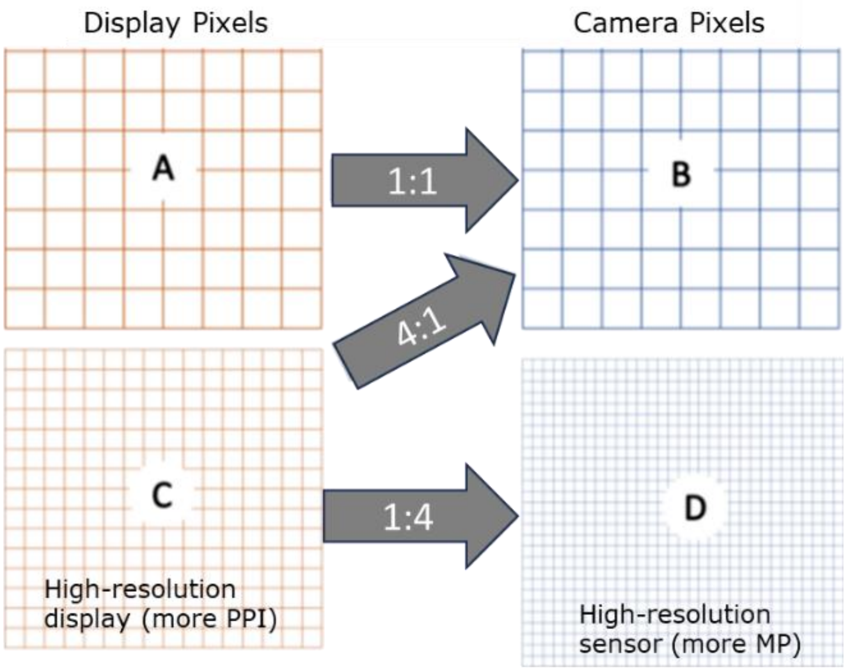


Sub-pixel imaging of a microLED display using Radiant ProMetric® Imaging Colorimeter plus Microscope Lens

Sensor Pixels vs. Display Pixels

Recommended: High-resolution image sensor

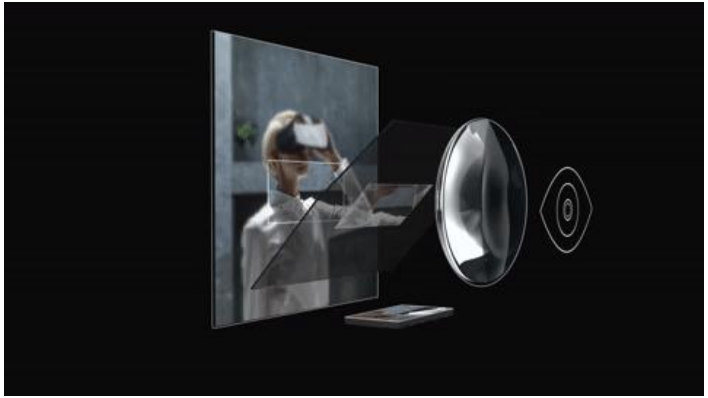
- High-resolution means more sensor pixels dedicated to each display pixel
- Able to capture precise detail of each display pixel and subpixel
- Single image is sufficient for faster measurement in production



Requirement: Focus

- Multi-focal, varifocal, and foveated optics create a need to measure more than 1 focal distance or region with a single measurement system

- Focal distances may dynamically change over a wide range (i.e., liquid lens optics)



Example of foveated optics from Varjo using two displays and a rotating combiner to adjust focal point. (Source: RoadtoVR)

Example of liquid lens optics used to produce "sweeping" focal points. (Source: https://doi.org/10.1145/3272127.3275015)

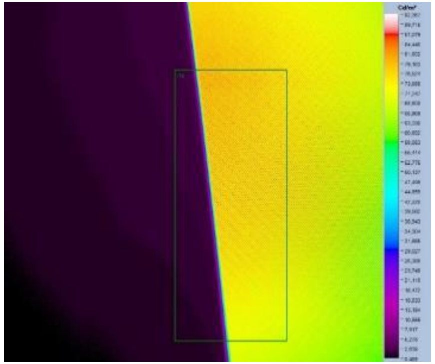
Challenge: Focus

How do we measure based on human eye focus region (fovea)?

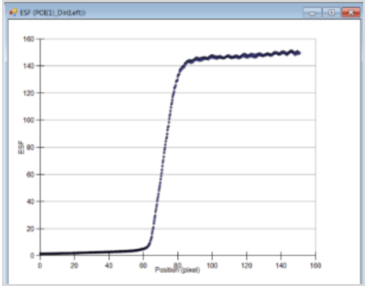
- Manual focus is imprecise and inconsistent
- Poor focus introduced by the imaging system impacts measurement accuracy

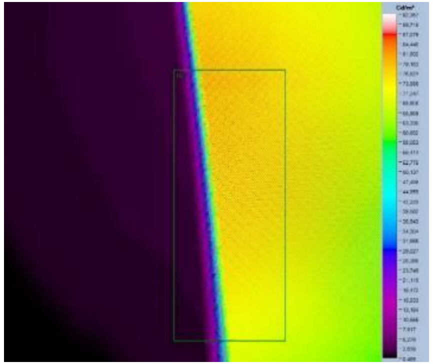
Recommended:
Automated electronic focus

Poor focus on edge impacts MTF result

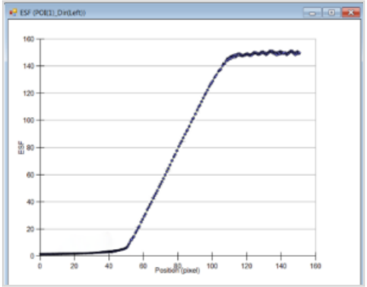


In-Focus





Poor Focus

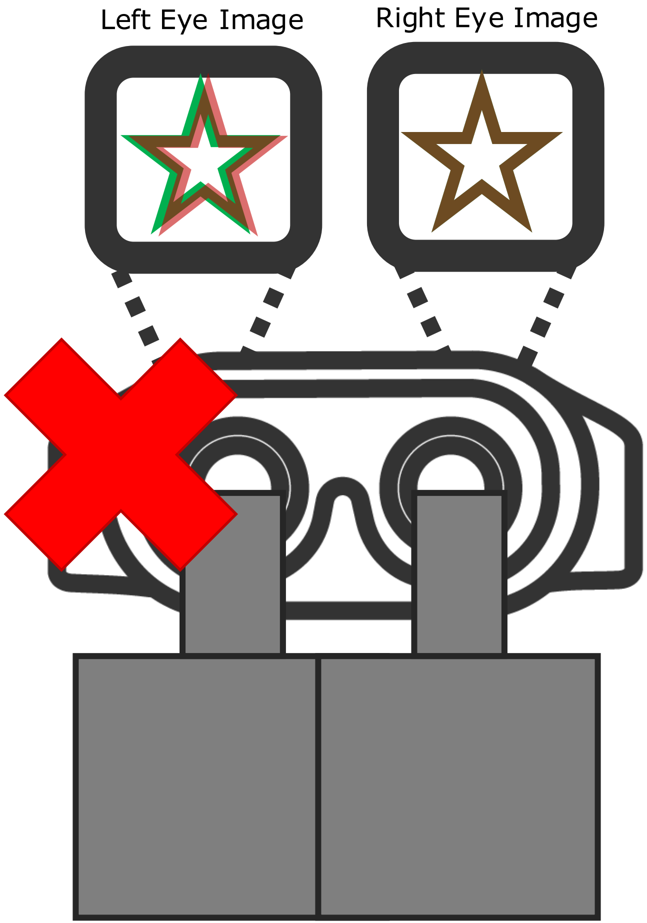


Challenge: Focus

How do we account for human binocular vision?

- Ensure consistency between left and right eyes
- Simultaneous measurement by 2 systems in the same headset

Recommended:
Flexible Lens design



Human Vision Characteristics

1 Perception of light and color

2 Size of human pupil

3 Pupil location / position

4 Human FOV

5 Human visual acuity (resolution)

6 Human foveal area (focus)

7 Binocular vision and interpupillary distance

Quality Test Solutions

Flexible optical solutions to address a range of unique measurement scenarios

Solution Design: System Optics

Requirement: Emulate Human Visual Characteristics

Human Vision		Test Solution
1	Perception of light and color	Accurate measurement of luminance and CIE-matched chromaticity
2	Size of human pupil	Aperture size
3	Pupil location / position	Location of test system entrance pupil within the headset
4	Human FOV	System FOV
5	Human visual acuity (resolution)	Sensor resolution
6	Human foveal area (focus)	Adjustable focus / focal distances
7	Binocular vision and interpupillary distance	Ability to perform dual-eye testing

Solution Options

ProMetric® Family of Imaging Systems

ProMetric® Y Imaging Photometers	
	• 16, 43, 61,151MP • Scientific image sensors • Broad dynamic range • Low image noise • Small form factor • Internal Tristimulus Y filter for photopic measurement • Electronically controlled lenses

ProMetric® I Imaging Colorimeters	
	• 2, 8, 16 & 61 MP • Scientific image sensors • Broad dynamic range • Low image noise • CIE-matched color filter wheel • Neutral density (ND) filter wheel • Electronically controlled lenses

LumiTop® X30

- Spectrally enhanced Imaging Colorimeter
- 31 MP image sensor

ProMetric® I-SC Solution

- Integrated imaging colorimeter + spectrometer
- 61 MP image sensor

Technical Features: XRE & XRF Lenses

Radiant XR Lenses: XR23, XR35, & XR57

- High MTF Measurement Capability
- High Resolution: up to 0.008° / sensor pixel
- Fold option: for ‘periscope’ measurement
- FOV Options: ±23°, ±35°, and ±57°
- Electronic Focus
- Focus Range: 0.5m to infinity
- Entrance Pupil Diameter: 1.33mm – 3.3mm
- Integrated Spectrometer available
- Low chromatic aberration through unique optical design
- Prescription Compensation: Spherical compensation with software-controlled electronic focus. Cylindrical compensation achieved via adjustable astigmatism corrector lens

Radiant XRF Lens

- High MTF Measurement Capability
- High Resolution: 0.007° / sensor pixel
- Fold option: for ‘periscope’ measurement
- FOV up to ±30°
- Manual Focus
- Focus Range: -4 to +4 Diopters
- Entrance Pupil Diameter: 1mm-5mm
- Integrated Spectrometer available
- low chromatic aberration through unique optical design
- Flat Image plane: Enables sharp-focus measurement of entire virtual image field of DUT.
- Prescription Compensation: Cylindrical compensation achieved via adjustable astigmatism corrector lens.

Radiant XR Measurement Solutions

AR/VR Lens

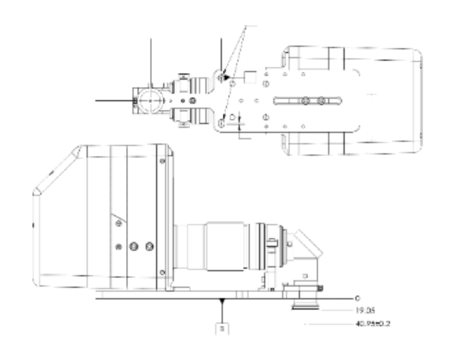
- Form factor fits inside XR headsets
- Front aperture replicates human pupil size and position
- FOV ± 60°

XRE Lens

- Replicates human eye in XR headsets
- Folded (periscope) and non-folded configurations
- Electronic lens and aperture control via software
- FOV ± 35°

Tailored Configurations

Modular components enable Radiant to configure an XR measurement solution to meet unique specifications



AR/VR Lens: Replicate the Human Eye

- Aperture (entrance pupil) size 3.6 mm is a typical human pupil
  - ➢ ***Simulates human eye pupil size***
- Aperture located on front of lens enables visibility to full display FOV
  - ➢ **Simulates position of human eye in headset**
- Aperture position and lens FOV combine to capture full 120° horizontal FOV
  - ➢ **Covers approximate FOV of binocular human vision**

Instrument Systems' ARVR Lens

Konica Minolta' Solution w/ adjustable external aperture

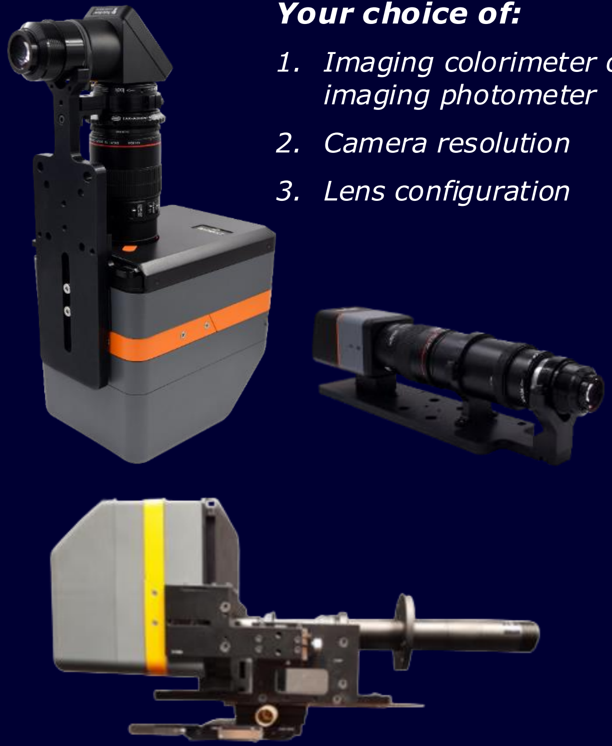
XRE/XRF Lens Flexible Optics

Flexible optical solution for replicating human vision in a broad range of XR devices & display test scenarios

- Two configurations:
  - Folded (“periscope”)
  - Non-folded (“straight”)
- Dual-eye measurement capability
- Electronic focus
- Paired with high-resolution ProMetric® Imaging Photometers and Colorimeters
  - Resolution options: 45, 61MP
  - FOV up to ±35° (70° total)
- XRF lens (pictured below): High MTF measurement capability with flat image plane

Your choice of:

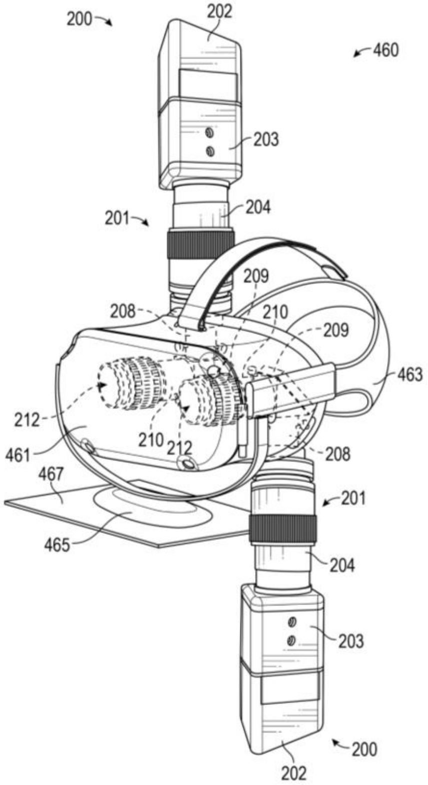
1. *Imaging colorimeter or imaging photometer*
2. *Camera resolution*
3. *Lens configuration*



XRE Lens: Folded Optics

- Folded optics provide more angles of approach to the desired imaging position
- **Dual-eye** (stereoscopic) measurement of left- and right-eye positions
- Two systems fit in the headset at once while continuing to avoid headgear

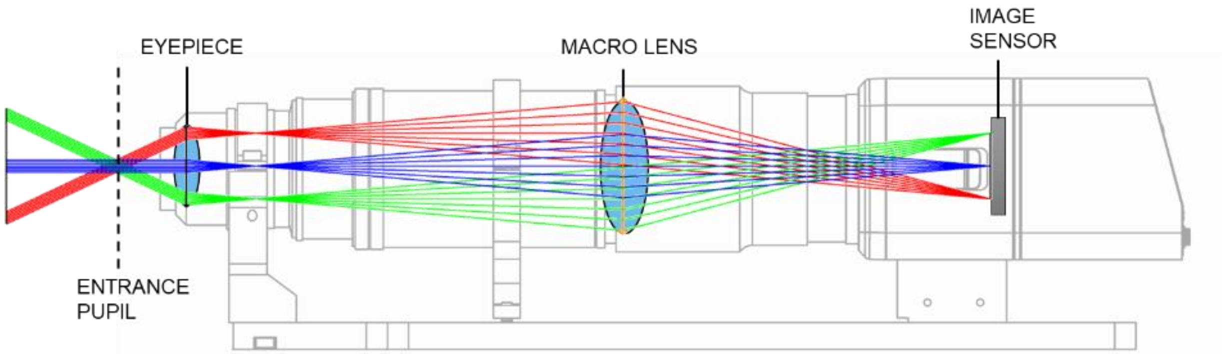
XRE Lens
Sample dual-eye configuration



Patent pending; Radiant Vision Systems LLC

Electronic Focus

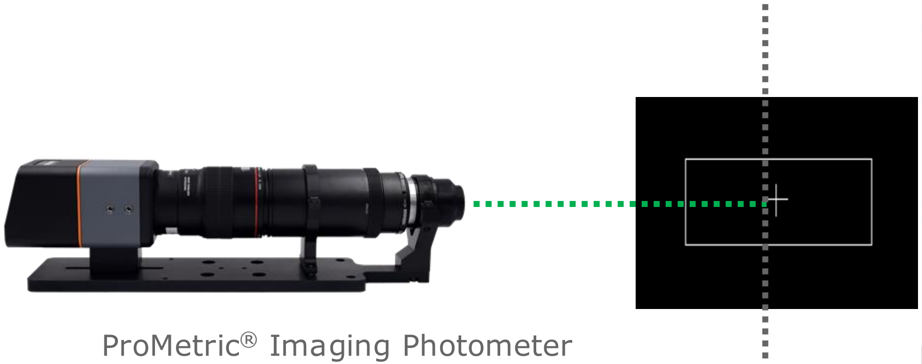
- Instantly adjust to multiple or variable focal planes
- Reduce measurement time, no need to reset
- Internal focus mechanism means lens barrel stays the same, no repositioning
- Set precise focal distances between 0.5 m and ∞
- Automated through-focus MTF measurement



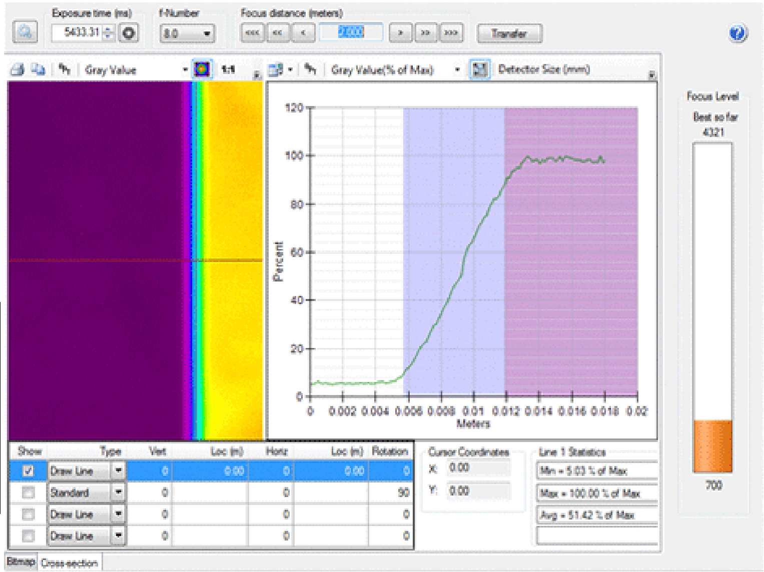
Radiant's XRE Lens

XRE Lens: Electronic Focus

Focus adjusted in software until the best focus (crisp edge) is found



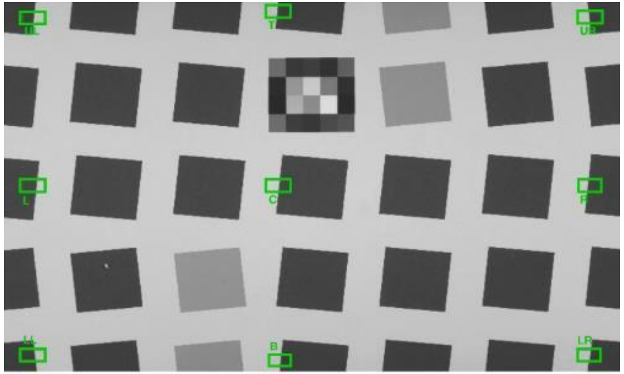
ProMetric® Imaging Photometer



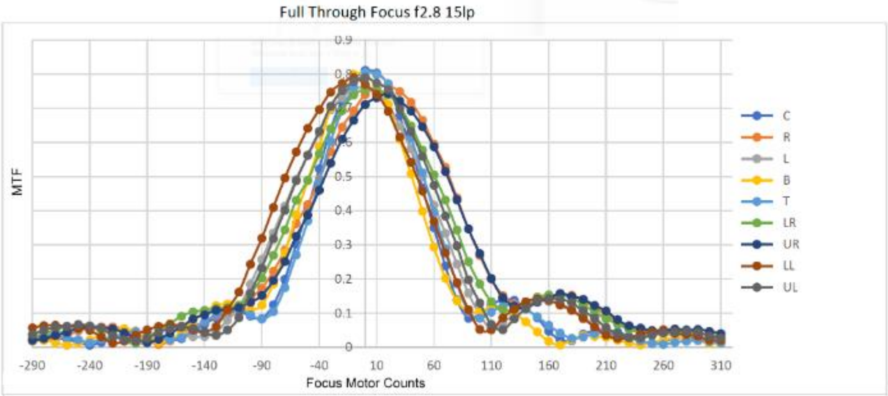
TrueTest™ Software

Focus

- Through-focus MTF testing finds best focus for each region of the display (based on MTF)
- Lens focus is iterated to record MTF at each focal distance
- No effective way to test with manual lens
  - Range of focal distances too great
  - Optimal focus of each region unknown
  - Each focus change significantly increases measurement time and risk of error

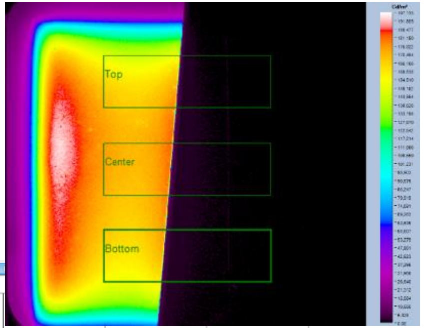


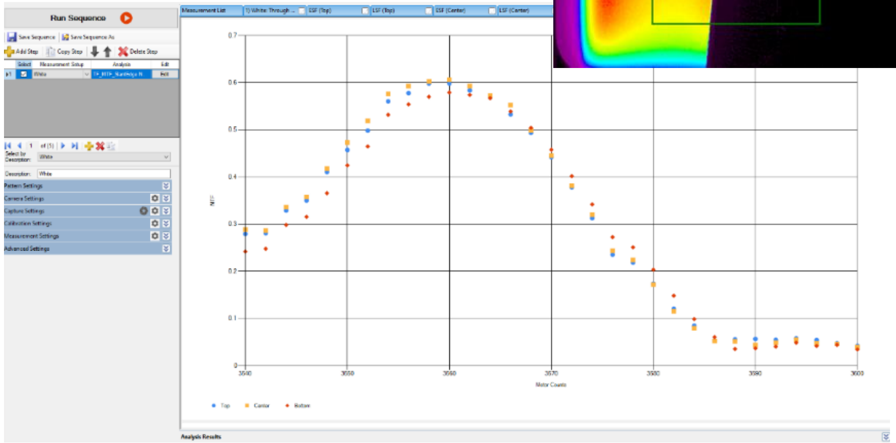
Key	UL = Upper Left	T = Top	UR = Upper Right
	L = Left	C = Center	R = Right
	LL = Lower Left	B = Bottom	LR = Lower Right



Electronic Focus: Through-Focus MTF

- Through-focus MTF test using XRE Lens system with electronic focus lens
- Lens barrel does not change length, so iterative measurements can be taken in rapid succession
- Focus changes are automated via software
- 30 focus settings for each measurement region completed in seconds



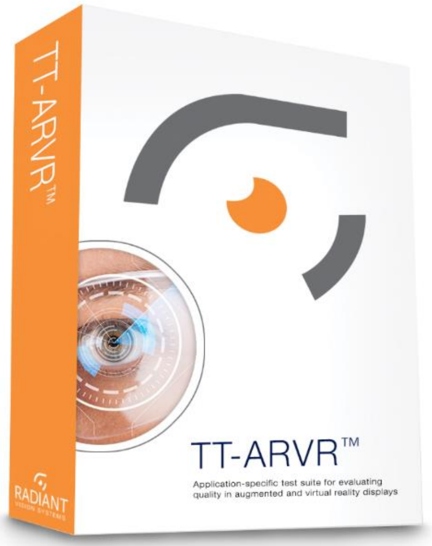


Measurements captured using the XRE Lens system and TrueTest™ Software from Radiant

Test Software & Automation

TrueTest TT-ARVR™ Software:
Analyses, features, and benefits for automated visual inspection

TT-ARVR™ Software



- Extensive library of measurement tests and analyses
- Controls test images on headset
- Synchronizes tests with images
- Rapid, automated evaluation of all visual qualities with pass/fail results
- API and SDK for integration with fixtures and control systems

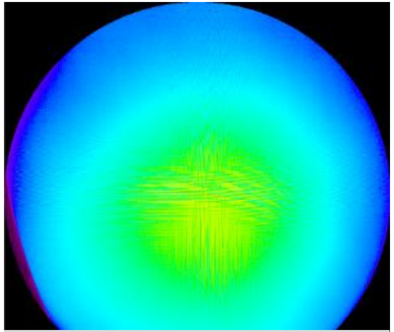
TT-ARVR Tests & Analyses

TT-ARVR Software Tests:

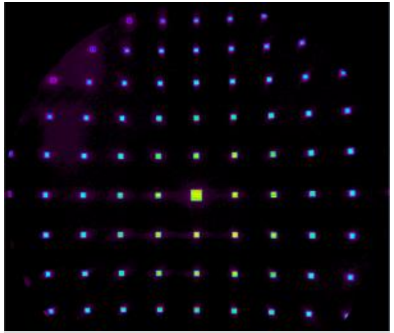
- ANSI Brightness
- ANSI Color Uniformity
- AutoPOI*
- Checkerboard Contrast
- Chromaticity
- Compare POI
- Contrast (Michelson)
- Distortion 9 Point
- Distortion Dot Grid*
- Distortion Line Grid Analysis*
- Field View (Reports actual FOV of the display in horizontal, vertical, and diagonal)*
- Focus Uniformity*
- MTF Line Pair
- MTF LSF (Line Spread Function)*
- MTF Slant Edge (ISO 12233)
- Through Focus MTF*
- Particle Defects
- Pattern Mura
- Pixel Defects
- Points of Interest
- Sequential Contrast
- Spatial xy Position*
- Uniformity (Mura) & Defects
- Demura (Mura Correction)*
- Warping Analysis

**Tests unique to RVS solution*

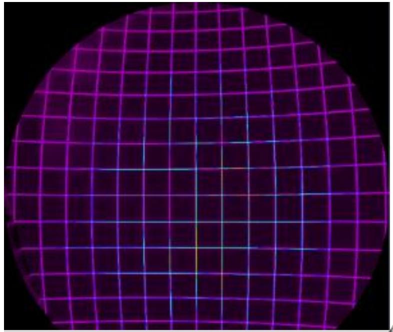
Application: In-Headset Display Testing



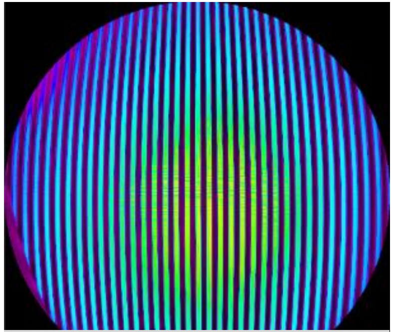
ANSI Brightness



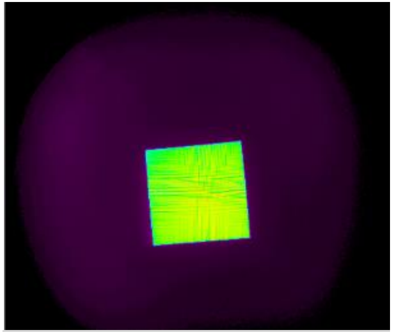
Distortion Dot Grid



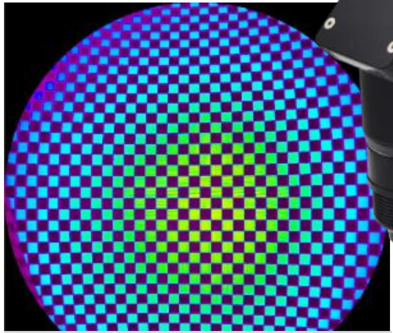
Distortion Line Grid



MTF Line Pairs



MTF Slant Edge



Focus Uniformity

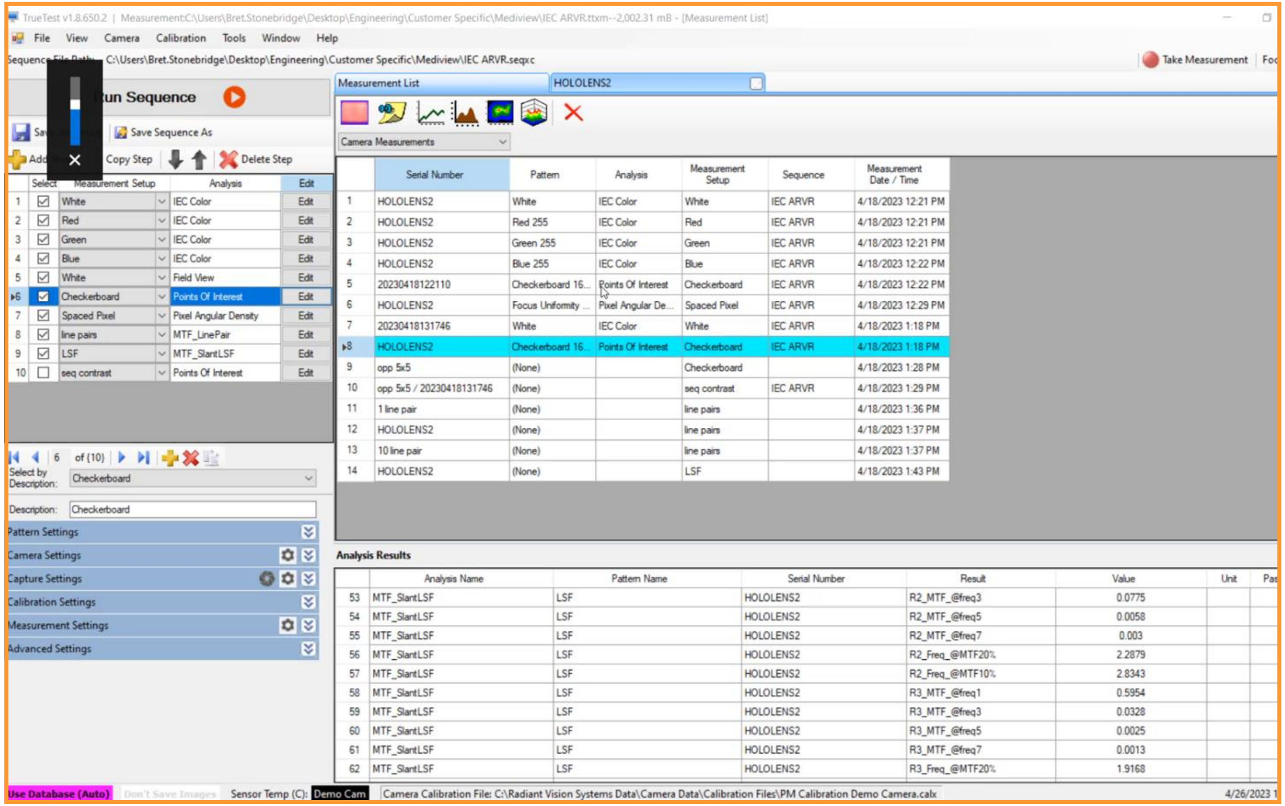
Example Standards: IEC

- **IEC 63145-20-20** Eyewear display – Fundamental measurement methods – Image quality
- Measurement methods, conditions, calculations
  - E.g., “light measurement device (LMD)”

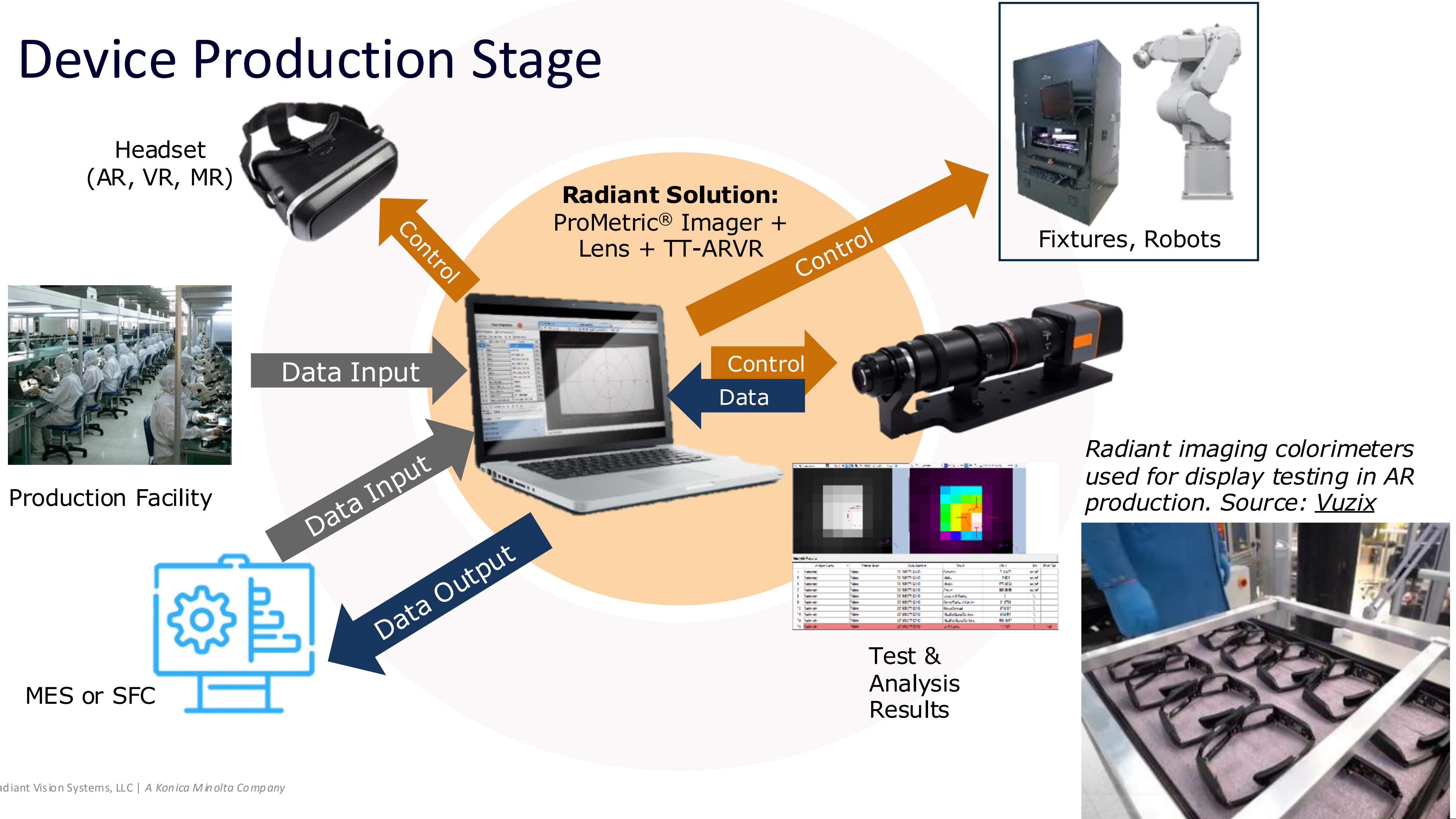
General XR Display Measurements
Spectral directional transmittance
Maximum center luminance
Luminance uniformity
Center contrast ratio
Diagonal FOV
Number of electrically addressable pixels
Eye-box width and height

AR Display Measurements	VR Display Measurements
All of the General XR Display Measurements	All of the General XR Display Measurements
Transmittance and luminance	Video see-through display luminance ratio
Luminance ratio of virtual image versus background (contrast)	

Example: IEC Criteria Test Sequence



Device Production Stage



Radiant imaging colorimeters used for display testing in AR production. Source: Vuzix

Summary

Summary

- Medical AR/VR devices and software present complex optical challenges and visual testing needs.
- Photometric imaging systems with high-resolution combined with purpose-built optics and software offer the most complete and effective solution to meet these needs
- Radiant's ProMetric cameras, **AR/VR Lens, XRE Lens, and TrueTest/TT-ARVR software** replicate human vision in more diverse measurement scenarios—from R&D to production.
- Radiant has the testing expertise you can rely on with support engineers located around the globe

Thank you!

Questions?

Info@RadiantVS.com
RadiantVisionSystems.com