2024

Handbook for Optical Measurement in VR

Contents

1. Introduction

The purpose of this manual is to provide a detailed introduction to the use of optical measurement equipment for the accurate measurement of Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) devices and their components. Although the main focus of the manual is on VR devices, the measurement methods provided are equally applicable to MR and AR devices. This manual covers:

- Applications
- Relevant technical standards and recommended methods
- Measurement settings
- Measurement steps and examples

2. Application

AR, MR and VR technologies merge the virtual world with the real world in different ways:

- **Virtual Reality (VR)**: the user is fully immersed in the virtual world through a VR device with no mixing with real world content.
- **Mixed Reality (MR)**: combining the virtual world with the real world through video perspective technology.
- **Augmented Reality (AR)**: superimposing virtual content onto the real world through see-through displays (e.g. waveguides).

2.1. VR/MR headsets

VR and MR headsets are typically designed to completely cover the user's field of view (see Table 1).

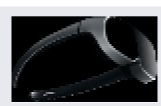
						
Meta Quest Pro	Playstation VR2	Pico 4	Valve Index	Apple Vision Pro	HTC Vive Focus 3	Nolo VR Glass

Table 1 : Different virtual reality headset designs

Prior to measurement, it is recommended to remove any accessories that may be in the way of measuring the optics. Also, to ensure that the test pattern is displayed as expected, it is preferable to call the hardware directly from the bottom. To reduce the risk of collision between the measuring device and the headset, it is preferred to measure from the bottom (see Figure 1).

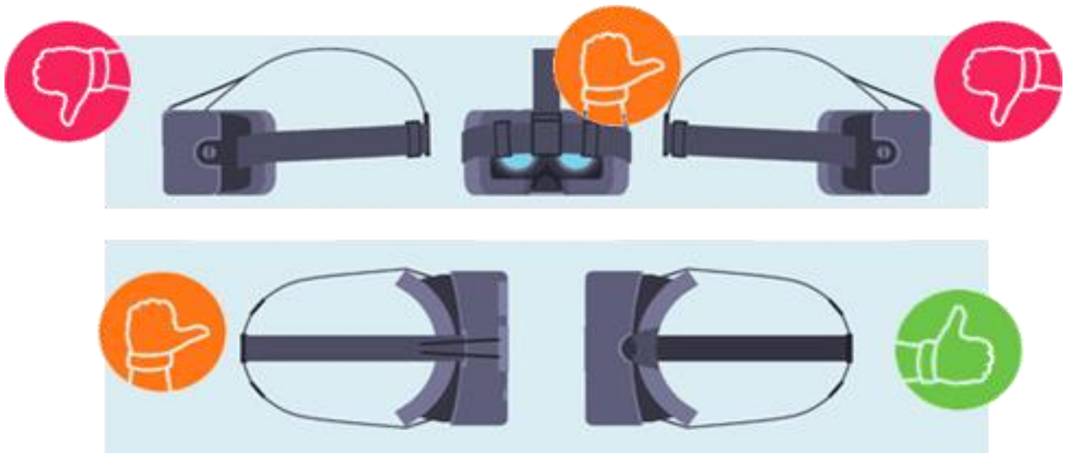


Figure 1: Measurements from the bottom are usually preferred to reduce the risk of collision with the helmet.

When performing binocular measurements (simultaneous measurement of both eyepieces of the helmet), sufficient space needs to be allowed for the light measuring device (LMD). For example, the pupil distance is usually between 60 mm and 75 mm, so the diameter of the LMD's lenses should be smaller than this pupil distance.

2.1.1. Components

In VR/MR devices, the image of the display is projected through a lens to the human eye (near-eye display). Depending on the design of the device, each display may have its own lens, or two lenses sharing a large display.
Displays typically utilize the following technologies:

- LCD (Liquid Crystal Display)
- OLED (Organic Light Emitting Diode)
- OLEDonSi (Organic Light Emitting Diode on Silicon)

Lenses are usually of the following types:

- Double Spherical Lens
- aspheric lens
- Fresnel lenses (Fresnel lenses)
- Pancake Lens

If the near-eye display includes a Pancake lens, a high-brightness display is required because its transmittance is only 10 to 25 percent.

2.2. AR headsets

AR headsets allow users to see the real world through a display screen and superimpose additional information or virtual content onto the view of the real world.

AR helmets are designed to be similar to regular sunglasses (see Table 2). Some designs take the form of a monocle.The development goal for AR helmets is to design devices that are lightweight and stylish so that they can be used around the clock. In principle, the considerations for measuring AR devices are the same as for VR devices (see Figure 1).

Table 2 : Overview of different augmented reality (AR) headset designs

2.2.1. Components

AR helmet designs strive for miniaturization and lightweight, often with compact displays and optics. The displays are designed to be extremely compact, measuring only a few cubic centimeters:

- Micro OLEDs (silicon-based organic light-emitting diodes)
- micro-LED
- LCOS (Liquid Crystal Silicon)
- LBS (Laser Beam Scanning)

In terms of the optics in front of the eye, a variety of types are used:

- beam splitter

- semi-reflective mirror
- prismatic lens
- wave guide
- Metal lenses or metal surfaces

Currently, waveguide is one of the most widely used technologies.

2.3. Measurement items

Optical measurements for virtual reality (VR) devices involve the following five key items:

- **Brightness (Uniformity)**: Measures the level of brightness that the device displays in different areas, and the uniformity of the distribution of that brightness. This is critical to ensure a consistent user experience.
- **Color (uniformity)**: Evaluates whether the device displays colors consistently in different areas. Color uniformity is as important to image quality as it is to the user experience.
- **Contrast ratio**: Measures the difference between the brightest and darkest parts of a display. A high contrast ratio helps to improve the clarity and sense of depth of an image.
- **Clarity**: Assesses the clarity and level of detail of an image. This is essential to ensure the legibility of text and images and the satisfaction of the overall visual experience.
- **Distortions**: detects if there are distortions in the image, especially in the edge areas. Distortions may affect the user's immersion and comfort.

Together, these measurement programs ensure that the visual performance of VR devices meets high standards to provide a high-quality immersive experience.

3. Definitions of common terms and coordinate systems

This section details the dimensional specifications and terminology associated with eyes, devices under test (DUTs), light measurement devices (LMDs), and augmented reality (AR)/virtual reality (VR) head-mounted display devices. The paper not only provides precise dimensional definitions for these devices, but also describes multiple coordinate systems. Specifically, the device under test (DUT) and the optical measurement device (LMD) each have a separate coordinate system. In addition, this document explains how these coordinate systems correlate with the position and viewing angle of the human eye to ensure measurement and display accuracy.

3.1. Eye-related dimensions and definitions

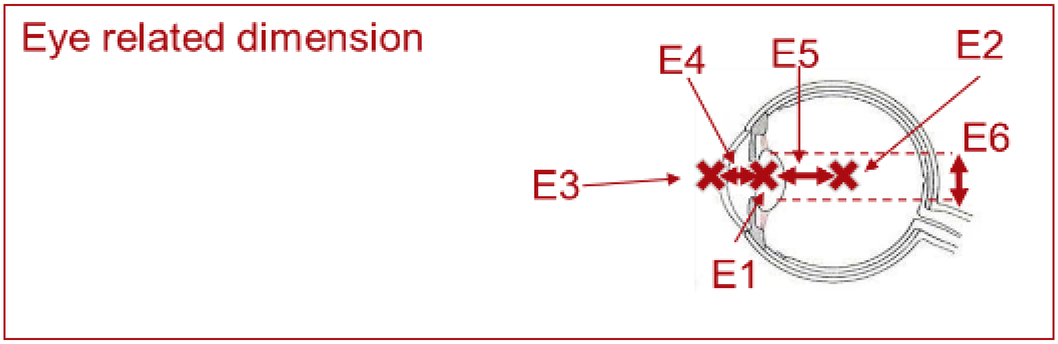


Figure 2: Eye-related dimensions

notation	name (of a thing)	descriptive
E1	pupil spot	The center of the eye into the pupil.
E2	eye rotation point	The center of the eye and also the center of eye rotation. Commonly used for measurements based on eye gaze, such as aberrations or MTF (modulation transfer function).
E3	corneal vertex (anatomy)	The most anterior point of the corneal surface.
E4	Distance from corneal apex to pupillary point	The distance between the corneal apex (E3) and the pupillary point (E1), with a standard value of 3 mm (IEC 63145-20-10/ICDM).
E5	Distance from the point of eye rotation to the pupil point	Distance between the point of rotation of the eye (E2) and the point of the pupil (E1), standardized to 10 mm (IEC 63145-20-10/ICDM).
E6	eye incidental pupil diameter (IpD)	The diameter of the eye's incoming pupil.

Table 3 : Eye-related dimensions and definitions

3.2. Dimensions and definitions related to the DUT (Device Under Test)

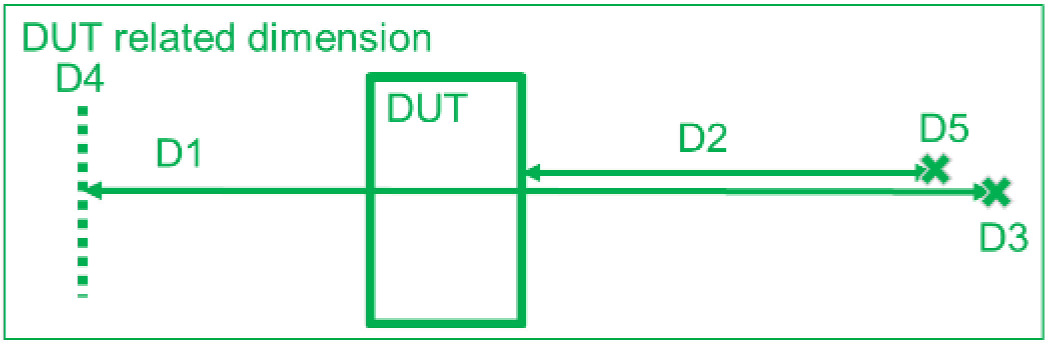


Figure 3 : DUT-related dimensions

notation	name (of a thing)	descriptive
D1	Virtual image distance or focal length	The distance between the eye point (D3) and the virtual image plane (D4).
D2	eye interval	Distance from the corneal vertex (D5) (of the eye) to the nearest optical element of the virtual image display device (IEC 63145-20-10). In practice, the eye interval is usually defined as the distance between the nearest optical element and the point of the eye.
D3	eyespot (in lower creatures)	Design position where the eye's entry pupil is placed for optimal performance when using an eyeglass display device and as the origin position for measurements (IEC 63145-20-10).
D4	Virtual image (flat)	Virtual image generated by the optics of the DUT.
D5	corneal vertex (anatomy)	The most anterior point of the corneal surface. d5 is the same as e3.

Table 4 : DUT-related dimensions and definitions

3.3. Dimensions and definitions related to Light Measuring Devices (LMD)

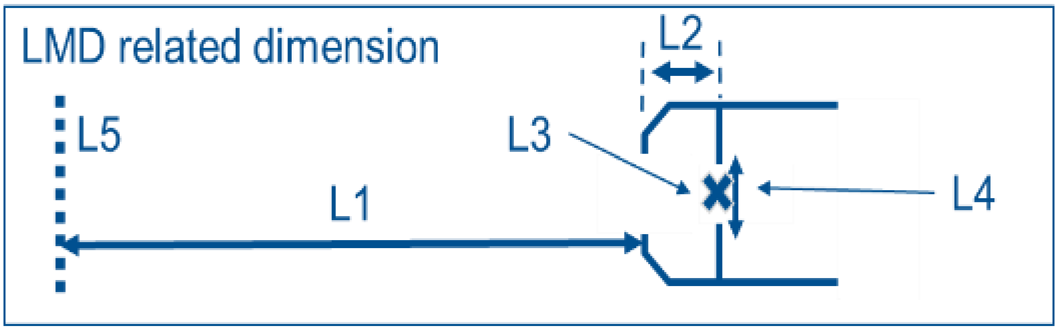


Figure 4 : LMD-related dimensions

notation	name (of a thing)	descriptive
L1	monitoring range	The distance from the lens to the focal point.
L2	Distance from the LMD entry pupil to the front surface of the photometric device	The distance between the LMD entry pupil (L4) and the front surface of the photometric device.
L3	LMD Pupil Point	LMD into the center of the pupil.
L4	LMD pupil diameter	The diameter of the LMD entry pupil.
L5	focal plane	The object plane at the focal length.

Table 5 : Dimensions and definitions related to optical measurement equipment

With a well aligned system, all corresponding points should overlap each other (see Figure 5).

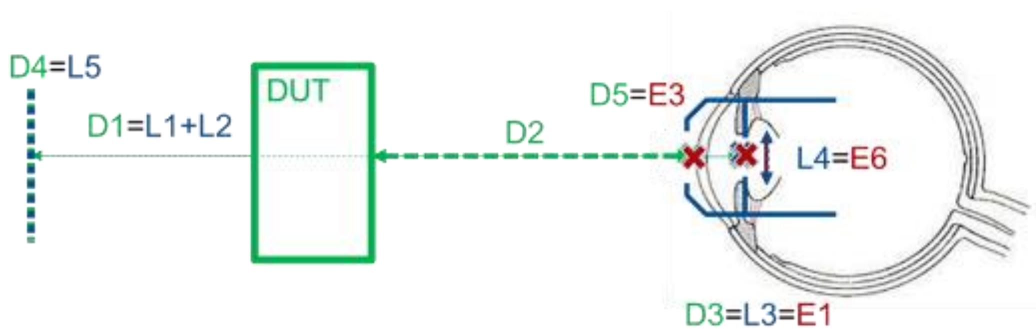


Figure 5 : shows the measuring device aligned to the DUT with the eye-related dimensions labeled

3.4. Coordinate system

There are two key coordinate systems in VR measurement:

- **DUT coordinate system**: defined by the device under test.
- **Measuring device coordinate system**: defined by the measuring device.

Coordinate system according to IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties, published by the International Electrotechnical Commission (IEC) in 2019 (see Figure 6).

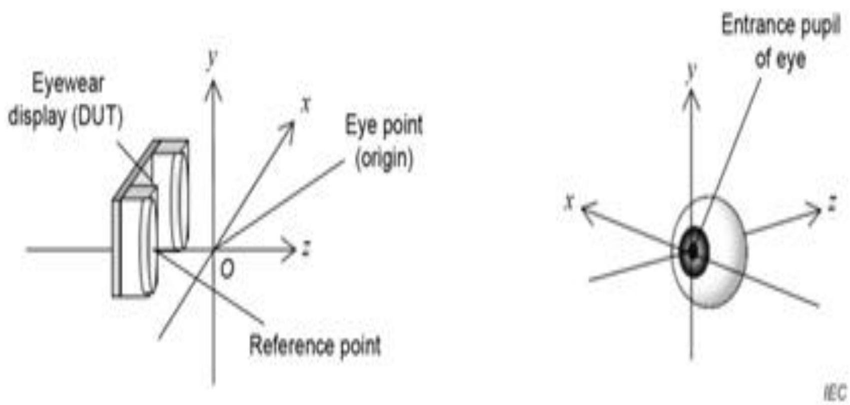


Figure 6 : Definition of the coordinate system, source: "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties".

If a simulated line of sight is required, the point of rotation of the eye should be used as the center of rotation (see Figure 7).

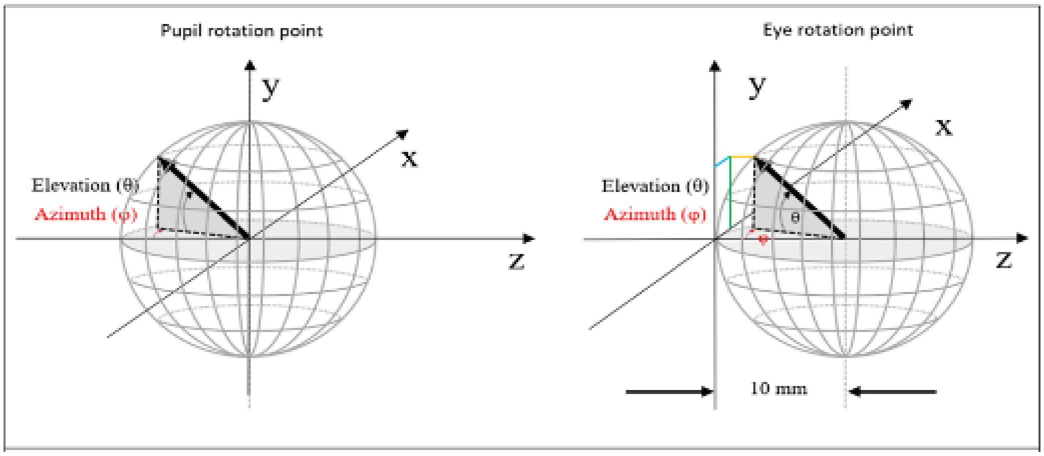


Figure 7 : Definition of the coordinate system, source: "ICDM - Information Display Measurements Standard-V1.1a, 2022" published by the Information Display Measurements Standard (ICDM)

3.5. Representation of different coordinate systems

To accommodate different application scenarios and personal preferences, AR/VR/MR applications allow users to choose from a variety of coordinate systems. In AR/VR/MR applications, Cartesian coordinate system or spherical (polar) coordinate system is usually used.

- **Cartesian coordinate system**: x, y, z
- **Spherical (polar) coordinate system**: θ, φ, R (where θ denotes the angle of elevation, φ denotes the azimuthal angle, and R denotes the distance to the origin, i.e., the radius of the sphere)

When performing aberration measurements, the Cartesian coordinate system is widely used because of its intuitive nature. When performing pixel density measurements, on the other hand, the spherical coordinate system is more applicable because it better reflects the distribution of pixels on the screen. In two-dimensional measurements, the representation of the coordinates is simplified because the depth information is not considered:

- **Cartesian coordinate system**: x, y
- **Spherical (polar) coordinate system**: θ, φ

4. Standard of measurement

Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR) devices follow a series of international standards that provide guidance on the optical measurements of the devices (see Table 1). As new standards are constantly being discussed and published by different organizations, any list is hardly complete. Although some of the standards were originally intended for flat panel display technology, their principles and technical requirements are largely applicable to near-eye display devices as well. The continuous updating and expansion of these standards ensures that the development of AR, MR and VR technologies keeps pace with technological innovations, as well as the consistency and security of the user experience.

Standards/organizations	**caption**
iec tr 63145-1-1:2018	Eyewear display - Part 1-1: Generic introduction
IEC 63145-1-2:2022	Eyewear display - Part 1-2: Generic - Terminology
IEC 63145-10:2023	Eyewear display - Part 10: Specifications
iec 63145-20-10:2019	Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties
iec 63145-20-20:2019	Eyewear display - Part 20-20: Fundamental measurement methods - Image quality
IEC 63145-21-20:2022	Eyewear display - Part 21-20: Specific measurement methods for VR image quality - Screen door effect
IEC 63145-22-10:2020	Eyewear display - Part 22-10: Specific measurement methods for AR type - Optical properties
iec 63145-22-20:2024	Eyewear display - Part 22-20: Specific measurement methods for AR type - Image quality
IEC TR 62977-1-31:2021/AMD1:2022	Amendment 1 - Electronic displays - Part 1-31: Generic - Practical information on the use of light measuring devices
iso 9241-333:2017	Ergonomics of human-system interaction - Part 333: Stereoscopic displays using glasses
iso/tr 9241-380:2022-06	Ergonomics of human-system interaction - Part 380: Survey result of HMD (Head-Mounted Displays) characteristics related to human-system interaction

DFF	Display Measurement Specification (DMS) for Automotive-TFT LCDs (V5.1, 2018) (Gamma)
ansi/infocomm 3m-201	Projected Image System Contrast Ratio
ICDM	Information Display Measurements Standard

Table 6 : Overview of standards related to AR/VR applications

4.1. IEC TR 63145-1-1:2018

IEC TR 63145-1-1:2018, published by the International Electrotechnical Commission (IEC), aims to provide a harmonized set of terminology and definitions for near-eye displays (NEDs) technology. The report, titled "Spectacle displays - Part 1-1: General introduction", is important for areas such as augmented reality (AR) and virtual reality (VR) headsets. The core purpose of the report is to create a common communication platform for manufacturers, developers, researchers, and other stakeholders to ensure consistent understanding and communication of near-eye display technologies. The report covers a wide range of optical systems, display technology types, and performance metrics, providing clear definitions of key terms in these areas:

- **Field of View (FOV)**: refers to the range of the environment that the user can observe through the display device at any given moment.
- **Resolution**: Describes the fineness of an image, usually measured in pixels per degree (Pixels Per Degree, PPD) or pixels per inch (Pixels Per Inch, PPI).
- **Refresh Rate**: Indicates how often the display device is updated per second, measured in Hertz (Hz).
- **Brightness and Contrast**: Used to evaluate the brightness level of the display device and the difference between the darkest and brightest parts of the image.
- **Optical distortion**: refers to the phenomenon of image distortion due to the optical characteristics of the display system.

It is important to note that IEC TR 63145-1-1:2018 is a technical report and not a formal standard. It only provides general information and recommendations and will not contain specific test methods and performance indicators. Therefore, in practice, it may be necessary to combine it with other relevant IEC standards or technical reports to fully evaluate the performance of near-eye displays.

4.2. IEC 63145-1-2:2022

IEC 63145-1-2:2022 is a standard issued by the International Electrotechnical Commission (IEC) to provide comprehensive guidance for Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR) systems, in particular eyewear displays. The full title of the standard is "Spectacle displays - Part 1-2: Common terminology." The core objective of IEC 63145-1-2:2022 is to establish a standardized set of terminology and framework for AR/VR spectacle systems to ensure consistency and clarity of communication within the industry. It covers in detail a number of key components and aspects of eyewear display systems:

- **System Architecture**: details the overall structure of the eyewear display system, including hardware and software components.
- **Optical system**: describes the optical components used in eyewear displays, such as lenses, waveguides, etc., which have a significant impact on the visual quality of the enhanced content.
- **Display technology**: list the display technologies used in eyewear, such as organic light-emitting diodes (OLEDs), liquid crystal displays (LCDs), and so on.
- **User Interaction**: explores the ways in which users interact with the content displayed by the glasses, including gesture recognition, eye tracking, and voice commands.
- **Performance Indicators**: Specify the key performance indicators of the eyewear display, such as field of view, resolution, brightness, contrast, latency, etc.
- **Ergonomics and safety**: Focusing on ergonomic design considerations and safety issues of eyewear to ensure comfort and safety.

By providing these guidelines, IEC 63145-1-2:2022 aims to drive the development, evaluation and standardization of eyewear display products, helping manufacturers, developers and researchers to create high-quality AR systems with a high degree of interoperability in line with industry standards.

4.3. IEC 63145-10:2023

IEC 63145-10:2023 is an important standard issued by the International Electrotechnical Commission (IEC) and is known as "Spectacle displays - Part 10: Specification requirements". The standard provides a comprehensive framework for eyewear display systems used in Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR) applications.The main objectives of IEC 63145-10:2023 encompass the following:

- **Establish common terminology**: Develop a standard set of terms and definitions for eyewear display systems to facilitate communication and understanding among relevant stakeholders.
- **Describe system components**: detail the major components and subsystems of an eyewear display system, including optical systems, display technologies, sensors, and user interface elements.
- **Clarify performance indicators**: Indicate the key performance indicators and their measurement methods for assessing the quality and effectiveness of eyewear displays, such as field of view, resolution, brightness, contrast, refresh rate, latency, and optical aberrations.
- **Emphasizes design considerations**: provides guidance on the design and ergonomics of eyewear display systems to enhance user comfort, safety, and overall experience.
- **Promote interoperability**: Ensure that eyewear display devices from different manufacturers can work together smoothly, and achieve this through standardized technology.

IEC 63145-10:2023 provides guidance to manufacturers, developers, researchers and other stakeholders in the development of high-quality, interoperable and user-friendly ophthalmic display systems by providing a comprehensive description of the principles and standards for ophthalmic displays. This standard is critical to advancing near-eye display technology and ensuring that the technology evolves to meet industry standards and user expectations.

4.4. IEC 63145-20-10:2019

IEC 63145-20-10:2019 is a standard published by the International Electrotechnical Commission (IEC) to provide harmonized test methods and standard conditions for the measurement of optical performance of eye-worn display devices. Eye-mounted display devices include virtual reality (VR) and augmented reality (AR) glasses, which utilize virtual image optics to display images to the user. The main purpose of this standard is to ensure that different manufacturers and testing organizations can use consistent and repeatable measurement methods when evaluating the optical performance of eye-mounted display devices, thereby improving the comparability and accuracy of measurement results.

The standard specifies various parameters for measuring the optical performance of eye-mounted display devices, including but not limited to luminance, luminance uniformity, contrast, chromaticity, color gamut, chromaticity uniformity, field of view (FOV), eye box, and angular pixel density, etc. These parameters are useful for evaluating the optical performance of eye-mounted display devices. These parameters are critical for evaluating the performance of eye-mounted display devices, as they directly affect the user experience, such as image quality, comfort and immersion. To enable these measurements, IEC 63145-20-10:2019 provides detailed measurement conditions and test procedures. These conditions include the setup of the test environment (e.g. lighting conditions, background color, test distance, etc.), as well as the requirements for the test equipment and measurement devices. The standard may also include guidelines for analyzing and interpreting measurement results to ensure the validity and reliability of test results.

By following this standard, eye wear display device manufacturers can ensure that the optical performance of their products meets specific quality and performance requirements, as well as assist consumers and industry users in selecting products that meet specific optical performance criteria. In addition, the standard is important for promoting interoperability and compatibility of eye wear display devices in the global marketplace.

4.5. IEC 63145-20-20:2019

IEC 63145-20-20:2019 is a standard published by the International Electrotechnical Commission (IEC) to provide harmonized test methods and standard conditions for image quality measurements of eye-worn display devices. Eye-mounted display devices include virtual reality (VR) and augmented reality (AR) glasses, which utilize virtual image optics to display images to the user. The main purpose of this standard is to ensure that different manufacturers and testing organizations can use consistent and repeatable measurement methods when assessing the image quality of eye-mounted display devices, thereby improving the comparability and accuracy of measurement results.

The standard specifies various parameters for measuring the image quality of eye-mounted display devices, including but not limited to distortion, color registration error, Michelson contrast, and focal length (diopter). These parameters are critical for assessing the image quality of eye-mounted display devices as they directly affect the user experience, such as image clarity, color accuracy and visual comfort. To enable these measurements, IEC 63145-20-20:2019 provides detailed measurement conditions and test procedures. These conditions include the setup of the test environment (e.g. lighting conditions, background color, test distance, etc.), as well as the requirements for the test equipment and measurement devices. The standard may also include guidelines for analyzing and interpreting measurement results to ensure the validity and reliability of test results.

By following this standard, manufacturers of eye-worn display devices can ensure that the image quality of their products meets specific quality and performance requirements, as well as assist consumers and industry users in selecting products that meet specific image quality criteria. In addition, the standard is important for promoting interoperability and compatibility of eye wear display devices in the global marketplace.

4.6. IEC 63145-21-20:2022

IEC 63145-21-20:2022 is an important International Standard published by the International Electrotechnical Commission (IEC) on July 27, 2022, to provide a harmonized standard for assessing the image quality of Virtual Reality (VR)-type eye-mounted display devices. This standard focuses on the measurement and evaluation of the Screen Door Effect (SDE) in eye-mounted display devices.

The Screen Door Effect is a common visual phenomenon in eye-mounted display devices, which describes a grid-like or line-like structure that appears visually when a user observes a display due to the spacing between pixels or black edges. This phenomenon may reduce the user's immersion and quality of experience, and thus the impact of the screen door effect needs to be minimized when designing and manufacturing VR eye-worn display devices.

To ensure that image quality can be fairly and accurately compared between devices, the IEC 63145-21-20:2022 standard provides a harmonized measurement method and standard conditions. These methods and conditions include methods for measuring the screen-gate effect in eye-mounted display devices, requirements for measurement equipment, requirements for the measurement environment, and methods for data processing and evaluation. By following these standards, manufacturers and test institutes can more accurately assess and optimize the image quality of eye-mounted display devices, thereby improving the quality of the user experience. The release of the IEC 63145-21-20:2022 standard plays an important role in promoting the development of VR technology and enhancing user experience. It not only provides a reliable reference standard for manufacturers, but also provides a reference basis for users when choosing and using VR eye-worn display devices. With the continuous development and application of VR technology, this standard will play an important role in the design and evaluation of future VR eye-mounted display devices.

4.7. IEC 63145-22-10:2020

IEC 63145-22-10:2020 is an International Standard published by the International Electrotechnical Commission (IEC) to provide a harmonized test and evaluation method for the optical characteristics of Augmented Reality (AR) eyewear displays. This standard was officially published on January 10, 2020 and focuses on the measurement of the transmissive optical characteristics and imaging quality of AR eyewear displays.

Augmented reality technology provides users with a new interactive experience by superimposing virtual information onto the real world.AR glasses, as the key carrier of this technology, have a direct impact on the user's sense of immersion and experiential effects due to their display quality. Therefore, accurately measuring and evaluating the optical performance of AR glasses displays is crucial to improving product quality and user experience. The

IEC 63145-22-10:2020 standard specifies standard conditions and methods for measuring the transmission characteristics, display performance under ambient light, and imaging quality of AR glasses displays. These conditions and methods include requirements for measurement equipment, requirements for the measurement environment, and methods for data processing and evaluation. By following these standards, manufacturers and test institutes can more accurately assess and optimize the optical performance of AR glasses displays, thereby enhancing the quality of user experience. The release of the IEC 63145-22-10:2020 standard plays an important role in promoting the development of AR technology and enhancing user experience. It provides a reliable reference standard for manufacturers and a reference basis for users when selecting and using AR glasses displays. In addition, the implementation of this standard will also help promote the healthy development of the AR glasses display market and drive the innovation and progress of the industry.

With the continuous development and application of AR technology, the IEC 63145-22-10:2020 standard will play an important role in the design and evaluation of AR glasses displays in the future. It not only provides a unified measurement method and standardized conditions for manufacturers, but also provides a reference for users when selecting and using AR glasses displays. By following these standards, manufacturers can more accurately evaluate and optimize the optical performance of AR Glasses Displays, thereby improving the quality of user experience.

4.8. IEC 63145-22-20:2024

IEC 63145-22-20:2024 was published on February 6, 2024 by the International Electrotechnical Commission (IEC). This standard is dedicated to the image quality of Augmented Reality (AR) type eye-worn display devices and specifies standardized conditions and measurement methods for measuring the image quality of these displays. It applies to see-through (AR glasses) eye-worn display devices that use virtual image optics. It should be noted that the standard does not apply to see-through type display devices (VR glasses), contact lens type displays and direct retinal projection displays.

A wide range of measurement conditions and methods are included in the standard, such as standard environmental conditions, power supply, warm-up time, darkroom conditions, etc. In addition, details of the measurement system are covered, including the standard coordinate system, measurement equipment, background and perspective real scene conditions. To ensure accurate measurements, the standard also provides settings for different test patterns, such as checkerboard patterns, solid color patterns and raster patterns. In addition, the standard contains a variety of parameter measurements related to virtual images and perspective real scenes, such as ambient contrast, ambient chromaticity and color gamut area, still image resolution, secondary image effects, flicker, etc. .

The publication of IEC 63145-22-20:2024 is important for improving the assessment of image quality in AR eye-worn display devices. It provides a unified measurement method and standardized conditions for manufacturers and testing organizations to ensure that optical performance can be fairly and accurately compared between different devices. This plays an important role in promoting the development of AR technology and enhancing user experience. By following these standards, manufacturers can more accurately assess and optimize the image quality of AR eye-worn display devices, thereby enhancing the quality of user experience.

4.9. IEC TR 62977-1-31:2021/AMD1:2022

IEC TR 62977-1-31:2021/AMD1:2022 is an international technical report on electronic displays which was published on March 14, 2022 by the International Electrotechnical Commission (IEC). This report provides practical information on the use of light measurement devices, including luminance meters, colorimeters and spectroradiometers, with optical systems for luminance measurement for characterizing electronic displays.

This report is a Technical Report type of publication and is intended to provide practical guidance and recommendations for the measurement of light in electronic displays. It covers the use of equipment such as luminance meters, colorimeters and spectroradiometers, which play a key role in evaluating and optimizing the performance of electronic displays. The publication of the report is important to ensure the accuracy and consistency of measurements of electronic displays in terms of brightness, color and spectrum.

It is important to note that IEC TR 62977-1-31:2021/AMD1:2022 is an amendment (Amendment) to the previously published IEC TR 62977-1-31:2021 standard, which aims to update and improve the content of the original standard. This demonstrates the IEC's continuous attention and updating of standards in the field of electronic displays in order to adapt to technological advances and market developments.IEC TR 62977-1-31:2021/AMD1:2022 is an important technical document in the field of electronic displays, which provides a set of harmonized measurement methodologies and practical guidelines for manufacturers, test institutes, and other interested parties, and helps to improve the quality and performance of electronic display products. display product quality and performance.

4.10.ISO 9241-333:2017

ISO 9241-333:2017 is a standard published by the International Organization for Standardization (ISO) focused on evaluating and ensuring the ergonomic (ergonomic) requirements of stereoscopic display devices for human system interaction. These devices enhance stereoscopic visualization by generating or facilitating binocular parallax, thereby providing users with a more immersive and realistic viewing experience. However, this stereoscopic display technology can also cause visual fatigue and discomfort, so specific ergonomic requirements are needed to ensure the effectiveness and comfort of users when viewing stereoscopic images.

The standard provides a series of test methods and metrics for evaluating the performance and user experience of stereoscopic display devices. These test methods include measuring parameters such as parallax, brightness and contrast, color accuracy, and field of view of stereoscopic images, as well as evaluating the user's visual comfort and stereo perception. By following these test methods and metrics, manufacturers can ensure that their stereoscopic displays meet ergonomic requirements and provide users with a high-quality stereoscopic visual experience.

ISO 9241-333:2017 applies to all types of stereoscopic display devices, including temporally or spatially interlaced types of display devices such as flat panel displays and projection displays. These devices typically use eyeglasses to separate the left and right eye images to produce a stereoscopic effect. The standard focuses on commercial and home leisure applications, such as watching movies and playing games, and specifies conditions for use in dark environments. The release of this standard is important for advancing stereoscopic display technology and enhancing the user experience. By following these standards, manufacturers can more accurately evaluate and optimize the performance of stereoscopic displays, thereby improving the quality of the user experience.

4.11.ISO/TR 9241-380:2022-06

ISO/TR 9241-380:2022 is an important document in the field of ergonomics of human-computer interaction, focusing on the characterization of head-mounted displays (HMDs) for interaction with human systems. This report is based on an in-depth analysis of the characterization of head-mounted displays and is intended to provide guidance to designers, developers, and researchers on how to better design HMDs.

ISO/TR 9241-380:2022 covers a number of aspects of HMDs, including display technology, optical performance, ergonomics, and interaction. All of these aspects have a significant impact on the user experience and therefore need to be considered in a comprehensive manner during the design process. For example, the choice of display technology will directly affect the clarity and color accuracy of the image, optical performance relates to the brightness and contrast of the image, ergonomics relates to the comfort and ease of use of the device, and the interaction mode determines the efficiency and ease of interaction between the user and the device.

In addition, ISO/TR 9241-380:2022 emphasizes the importance of user experience. Since HMDs are used in a variety of scenarios, including gaming, education, medical care, etc., they need to be optimized for different usage scenarios in order to meet users' needs. For example, in gaming, HMDs need to

provide high responsiveness and low-latency interaction, while in the medical field, they need to provide high definition and accurate image display.
ISO/TR 9241-380:2022 provides an important reference and guidance for the design and development of head-mounted displays. By comprehensively considering multiple aspects, it can better meet user needs and provide a better user experience. With the continuous development of HMDs technology and the expansion of application scenarios, this document will become more and more important, and is of great significance in promoting the development and application of HMDs technology.

4.12. Display Measurement Specification (DMS) for Automotive-TFT LCDs (V5.1, 2018) (Gamma)

The Display Measurement Specification (DMS) for Automotive TFT LCD Displays (V5.1, 2018) is a standard or guideline on Gamma correction. This specification focuses on how to accurately measure the Gamma correction for automotive displays, which is important to ensure accurate display of images and colors.

This specification includes the following main aspects:

- **Definition of Gamma Curve**: Specifies the standard of Gamma curve that the display should achieve. This curve determines the relationship between the input signal and the display brightness.
- **Measurement Methods**: Details on how to accurately measure the Gamma calibration of a TFT LCD display, including what equipment to use, how to perform the calibration, and in what environment to perform the measurement.
- **Performance Requirements**: Gamma-corrected performance standards are set to ensure that the display provides a consistent and accurate color display at different brightness levels.
- **Compliance and Certification**: Provides guidance to manufacturers on how to ensure their products meet Gamma calibration standards, which may include a range of testing and certification processes.
- **Industry application**: For the special application of automotive displays, automotive-specific factors such as ambient light, viewing angle and durability are taken into account.

Following this specification allows manufacturers to produce TFT LCD displays with accurate color and consistent performance.

4.13. ANSI/Infocomm 3m-201

ANSI/INFOCOMM 3M-201 is a standard published jointly by the Audio Visual and Integrated Experience Association (AVIXA, formerly InfoComm International) and the American National Standards Institute (ANSI). The standard is entitled "Contrast Ratio for Projected Image Systems - Measurement and Specification". It outlines a methodology for measuring and standardizing the contrast ratio of projection image systems, which is critical for evaluating the performance and quality of projectors used in a variety of audio visual (AV) applications.

Key aspects covered by ANSI/INFOCOMM 3M-201 include:

- **Measurement Methods**: Defines standardized procedures and equipment used to accurately measure the contrast ratio of a projected image system. This includes guidelines for setting up test conditions, using appropriate test patterns and considering ambient light.
- **Contrast Ratio Calculation**: Provides a method of calculating the contrast ratio based on peak white light brightness and black level measurements. The contrast ratio quantifies the difference in brightness between the brightest and darkest portions of the projected image.
- **Reporting Requirements**: specifies how measured contrast ratios should be reported to ensure consistency and clear communication between manufacturers, integrators, and projection system users.
- **Application and Compliance**: Provides guidance for manufacturers and integrators to ensure that their projection systems meet specified contrast ratio requirements. Compliance with this standard helps ensure consistent image quality and performance in different projection environments.

ANSI/INFOCOMM 3M-201 plays a key role in benchmarking image quality for projection systems, providing a standardized method for evaluating and comparing the contrast performance of projected images for use in educational, corporate, entertainment, and other AV scenarios.

4.14. Information Display Measurements Standard

The International Commission on Display Measurement's (ICDM) Information Display Measurement Standard is a set of rules that guide how to measure and evaluate the performance of electronic displays. This standard is important because it helps ensure consistency and accuracy in the quality assessment of different types of displays, such as LCDs, OLEDs, and displays used in areas such as consumer electronics, automotive, and medical devices.

This standard includes the following main aspects:

- **Measurement Methods**: Details on how to measure various key characteristics of the display, such as brightness, color range, contrast, resolution, response time and viewing angle.
- **Performance Metrics**: Specifies how the metrics used to describe the performance of the display are calculated and reported, ensuring that measurements are fair and comparable.
- **Calibration and setup**: Advice is provided on how to calibrate the measurement equipment and how to set up the test environment to minimize the impact of external factors on the measurement results.
- **Environmental conditions**: Recommended environmental conditions that should be controlled when performing measurements to ensure consistency of results.
- **Reporting Requirements**: specifies how measurements should be reported to facilitate clear communication and comparison of display performance data between parties.

This standard is important for display developers, evaluators and quality assurance personnel. Adherence to the standard helps them to ensure that displays meet established performance criteria and provide a consistent and satisfactory user experience across a wide range of applications and environmental conditions.

5. Optical measurement equipment

5.1. LMD equipment specification requirements

IEC-63145-20-10:2019 Standard:

According to IEC-63145-20-10:2019, the incident pupil diameter of the optical measuring device should be between 2 mm and 5 mm and should not be larger than the output light field of the device under test (DUT). At the same time, the angular accuracy of the device should be controlled within 0.1°, and the positioning accuracy of the translation stage should be 0.05 mm or better with respect to the Light Measuring Device (LMD)/Device Under Test (DUT).

ICDM standards:

According to the ICDM (Information Display Measurements Standard-V1.1a, 2022) standard, the recommended angular accuracy is 0.05°, which can be relaxed to 0.1° in specific cases. The accuracy of the panning table should be 0.1% of the diagonal of the display screen.

5.2. LMD Functional Requirements

The Imaging Light Measurement Device (ILMD) should be able to provide a 2D image of the Device Under Test (DUT). For comparison with data from a point light measurement device (LMD), it is often necessary to convert between Cartesian and spherical coordinate systems depending on the different fields of view (FOV) of the device If the ILMD supports polar coordinates, they should be used preferably for comparison, e.g., when comparing with a photometric device.

5.2.1. Imaging Light Measuring Devices (ILMD) Standard

IEC-63145-20-10:2019 Standard:

- The spectral range measurement shall be from 380 nm to 780 nm.
- The bandwidth should be less than 5 nm.
- The wavelength accuracy should be less than 0.3 nm.
- The 2D imaging LMD should be a filter type LMD.
- The number of pixels in the 2D imaging LMD shall be not less than four times the number of subpixels of the virtual image in the measurement field.

ICDM standards:

- **Luminance measurements**: For luminance measurements of CIE A sources, it is required that the relative uncertainty of the measurement results (taking into account a 2-fold coverage factor) does not exceed 4% and that the repeatability error over a 5-minute period does not exceed 0.4%. In addition, the deviation of the relative spectral responsivity of the measuring device from the V(λ) curve should be less than or equal to 8%.

- **Illumination measurements**: In the case of illumination measurements of CIE A light sources, the relative uncertainty of the measurement results (taking into account a 2-fold coverage factor) shall not exceed 4%, and the repeatability error within 5 minutes shall be less than 0.4%. The deviation of the relative spectral responsivity from the V(λ) curve should be less than 8% and the directional response error should not exceed 2%.

- **Chromaticity measurements**: For chromaticity measurements of CIE A light sources, all measuring devices shall have an extended uncertainty (taking into account a 2-fold coverage factor) of not more than 0.005 and a repeatability error of less than 0.002 in the determination of the CIE 1931 (x,y) chromaticity coordinates.

- **Measurement of radiant brightness**: For spectroradiometers covering the range 380 nm to 780 nm, the relative extended uncertainty (taking into account a 2-fold coverage factor) should be less than or equal to 2% for the range 400 nm to 700 nm, and less than or equal to 5% for the ranges 380 nm to 400 nm and 700 nm to 780 nm.

- **Array detector measurements**: For luminance measurements of CIE A source homogeneous sources, the relative uncertainty of the measurement results (taking into account the 2x coverage factor) shall be no more than 4%, and the repeatability error over a 5-minute period shall be less than 0.4% when using an array detector. The deviation of the relative spectral responsivity from the V(λ) curve shall be less than 8%, and the mean value of any 10 × 10 pixel measurement area shall be within 2% of the mean value of the entire array at 50% ± 10% saturation.

5.2.2. Goniophotometer standards

IEC-63145-20-10:2019 Standard:

- Spectral range: 380 nm - 780 nm.
- Bandwidth: < 5 nm.
- Wavelength accuracy: < 0.3 nm.
- Biaxial photometer.
- Angular accuracy: ≤ 0.1°.
- Three-axis translation table: accuracy of translation ≤ 0.05 mm.

5.3. Measurement Scenarios

Depending on the requirements, there may be different measurement scenarios. The key is whether the pupil point (pupil point) or eye rotation point (eye rotation point) is used for the measurement. When a direct comparison of a 2D photometric device with a point photometric device is required to evaluate the full field of view of the DUT, this situation falls under type 3 (see Table 7).

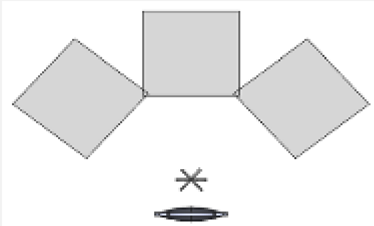
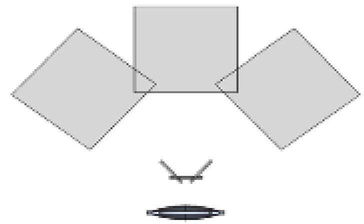
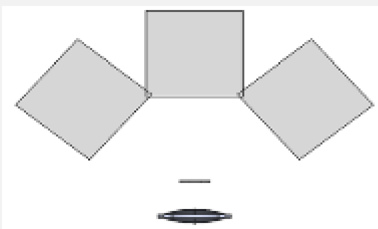
Alignment type	**schema**
Type 1: Pupil fixed to LMD **Rotation point: pupil point** When the LMD is rotated, a different view of the DUT can be seen and the measurement aperture changes. Does not reflect natural reality.ICDM recommends this method.	
Type 2: Pupil fixed to LMD **Rotation point: eye movement point** When the LMD is rotated, different viewing angles of the DUT can be seen, and the measurement aperture changes accordingly, reflecting natural reality.IEC recommends this method.	
Type 3: Pupil not fixed to LMD **Point of rotation: pupil point** When the LMD is rotated, a different view of the DUT can be seen while the measurement aperture remains constant. Maintaining a non-tilted view of the DUT is critical when using a 2D photometric device in comparison to a point photometric device.	

Table 7 : Different types of LMD and field of view combinations (note: gray boxes represent LMDs, lenses represent DUTs, and the thin line between represents the field of view or aperture)

6. Test Methods

In this section, for each test method, we will provide the following four landmark tips to clarify whether a 2D Light Measurement Device (2D LMD) or a Spot Light Measurement Device (Spot LMD) is appropriate. Additionally, these tips will guide us as to whether or not we need to adjust the position of the photometric device when performing a particular test method.

- ☒2D: for 2D light measurement equipment

- ☒ Point: for point light measurement equipment
- ☒ Moving point: the point light measurement device needs to be moved during the test process
- ☒ Moving 2D: 2D photometric equipment needs to be moved during testing

6.1. Eye point alignment

According to "ICDM - Information Display Measurements Standard-V1.1a, 2022", the accuracy of the eye alignment should be within +/- 1 mm (x, y coordinates).

6.1.1. Eye point alignment (ICDM)

- ☒2D
- Points
- Moving Points
- ☒Mobile 2D

In accordance with "ICDM - Information Display Measurements Standard-V1.1a, 2022", the standard for an eye point (eye box) is typically determined by selecting a specific attribute or dimension, such as 50% of a maximum value. Available attributes or dimensions include, but are not limited to:

- luminance
- contrast ratio
- Michelson Contrast
- color
- geometric distortion

measurement step

1. Use the appropriate measurement pattern.
2. Move the LMD in the -x direction until it reaches the standard position ($x_{1,j}$) (j represents the number of iterations).
3. Move the LMD in the x direction until it reaches the standard position ($x_{2,j}$).

4. Determine the midpoint between -x and x ($x_{m,j}$).
5. Set the midpoint to the new zero point of the$x_{m,j}$.
6. Move the LMD in the -y direction until it reaches the standard position ($y_{1,j}$).
7. Move the LMD in the y direction until it reaches the standard position ($y_{2,j}$).
8. Determine the midpoint between -y and y ($y_{m,j}$).
9. Set the midpoint to the new zero point of the$y_{m,j}$.
10. Repeat steps 2 through 9 until the change in zero is less than 1 mm.

calculation method

The formula is as follows:

Repeat the above steps until:

$$x_{m,j} - x_{m,j-1} < 1mm$$

$$y_{m,j} - y_{m,j-1} < 1mm$$

Reporting requirements

The report should contain the absolute coordinates of the final eyepoint position for the current eyepiece, the type of LMD, the setup conditions, the test pattern, the alignment method, and the attributes and threshold values used to determine the boundaries of the eyepiece box.

6.1.2. Eye point alignment using crosshairs (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

Please refer to "ICDM - Information Display Measurements Standard-V1.1a, 2022" for more details. This method is applicable to 2D optical measurement equipment or direct visual inspection.

measured parameter

- Line width of the crosshair pattern
- Brightness of the crosshair pattern
- Degree of distortion of the crosshair pattern

Note: 2D photometric equipment should have sufficient resolution to accurately detect crosshair patterns.

6.1.3. Eye point alignment using center brightness (ICDM)

- ☒2D
- Points
- Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for more details. This method is applicable to 2D optical measurement devices or point LMDs.

measured parameter

- luminance

Note: A 2° measured field of view with a 50% reduction in brightness is used as a criterion for judging.

6.1.4. Eye point alignment using center resolution (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for more details. This method is applicable to 2D optical measurement devices.

measured parameter

- Michelson Contrast

Note: Judged by a 50% drop in Michelson contrast.

6.1.5. Eye point alignment using field of view (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for more details. This method is applicable to 2D optical measurement devices.

measured parameter

- field of view

Note: The field of view (FOV) of a 2D LMD should be larger than the device under test (DUT). Reduce the FOV area to 95% as a criterion.

6.1.6. Centering of NED eyeboxes using lateral chromatic aberration (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for more details. This method is applicable to 2D optical measurement devices.

measured parameter

- lateral color difference

Note: To ensure accurate analysis, the 2D LMD system should have sufficient resolution to clearly identify barcodes in the test pattern as well as sub-pixel level features of the device under test (DUT).

6.1.7. Centering of NED eye boxes using coma, astigmatism, and field curvature (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for more details. This method is applicable to 2D optical measurement devices.

measured parameter

- optical aberration

Note: In order to accurately resolve sub-pixel features, the resolution of the 2D LMD system should be at least four times the feature size of the device under test (DUT). Such a resolution ensures that each test pattern point can be covered by at least four pixels in the image. If the resolution is insufficient, resulting in a failure to achieve at least four-pixel coverage of each point, the field of view (FOV) of the 2D LMD may be limited to less than 10°.

6.1.8. Eye-point alignment using the full-field-of-view luminance method (IEC-63145-20-10:2019)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

For further details see "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties". This method is applicable to 2D optical measurement devices.

measured parameter

- luminance

Note: A 50% reduction in brightness and a 95% reduction in image area are used as judging criteria.

6.1.9. Eye point alignment using the Michelson contrast method (IEC-63145-20-10:2019)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

For further details see "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties". This method is applicable to 2D optical measurement devices.

measured parameter

- Michelson Contrast

Note: Judged by a 50% drop in Michelson contrast.

6.1.10. Comparison between different eye alignment techniques

methodologies	eye alignment	Eye alignment using cross hairs	Eye alignment using center brightness	Eye alignment using center resolution	Eye alignment using the field of view	Centering of NED eyeboxes using lateral chromatic aberration	Centering of NED eye boxes using coma, astigmatism, and field curvature	Eye-point alignment using the full-field-of-view luminance method	Eye-point alignment using the Michelson contrast method
LMD type	Dot/2D	2D	Dot/2D LMD Field Angle 2°	2D LMD FOV > FOV Virtual Image	2D	2D	2D LMD resolution should be at least four times that of the DUT	2D	2D
test pattern		crosshairs	fig. reactionary	fig. reactionary	Grid pattern	color	color	fig. reactionary	Grid pattern
Criteria for judging	Standard definition of the center of the eye frame	Eye point equals optimal imaging of the pattern	The eye point is the center of the eye frame where the brightness drops to 50 percent	The eye point is the center of the eye frame with a 95% field of view	The eye point is the center of Michelson's contrast drop to 50% of the eye frame	The eye point is the location with the smallest color difference from a color such as green. Only for DUTs with	The eye point is the location of the smallest fractional area. Only for DUTs with measurable coma, astigm	The eye point is the center of the eye frame with the largest luminance region size. The luminance region size is	The eye point is the center of Michelson's contrast drop to 50% of the eye frame

						measurable color difference	atism or field curvature	defined as decreasing to 50 percent	

Table 8 : Comparison between different eye-point alignment techniques

Note: Of the various methods discussed, a basic requirement is to ensure that the positional positioning between the DUT and the LMD is accurate, and in particular the angle setting between the DUT and the LMD needs to be able to be realized repeatedly.

6.2. Luminance Measurement

6.2.1. Luminance measurement (IEC-63145-20-10:2019)

- ☒2D
- Points
- Moving Points
- ☐Mobile 2D

See "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- luminance

6.2.2. Luminance and contrast uniformity measurement (ICDM)

- ☒2D
- Points
- Moving Points

- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- Brightness (white, red, green, blue)
- ferrous
- contrast (balance of black and white in TV screen setup)

6.3. Chromaticity and color gamut measurements

6.3.1. Chromaticity and color gamut measurements (IEC-63145-20-10:2019)

- ☒2D
- Points
- Moving Points
- ☐Mobile 2D

See "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- Chromaticity coordinates x, y (red, green, blue)
- Color gamut area (xy)

6.3.2. Chromaticity Color Gamut Area Uniformity Measurement (ICDM)

- ☒2D
- Points

- Moving Points
- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- Chromaticity coordinates x, y (red, green, blue)
- Color gamut area (xy)

6.4. Chromaticity Uniformity Measurement

6.4.1. Measurement of colorimetric homogeneity (IEC-63145-20-10:2019)

- ☒2D
- Points
- Moving Points
- ☐Mobile 2D

See "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

When evaluating chromaticity uniformity, the maximum color distance is used as a criterion.

6.4.2. Colorimetric uniformity measurement (ICDM)

- ☒2D
- Points
- Moving Points

- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or point LMD.

measured parameter

- Chromaticity u', v' (white, red, green, blue, black)
- White color uniformity

6.5. Contrast measurement

6.5.1. Contrast measurement (IEC-63145-20-10:2019)

- ☒2D
- Points
- Moving Points
- ☐Mobile 2D

See "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- contrast (balance of black and white in TV screen setup)

6.5.2. Measuring Contrast in Tessellated Patterns Using Large Field of View LMDs (ICDM)

Alias ANSI contrast ratio.

- ☒2D
- ☐ Point
- ☐ Moving Points

- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMDs.

measured parameter

- White, Black Brightness
- contrast (balance of black and white in TV screen setup)

6.5.3. Measuring Contrast in Tessellated Patterns Using Small Field of View LMDs (ICDM)

- ☒2D
- Points
- Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or point LMD.

measured parameter

- luminance
- contrast (balance of black and white in TV screen setup)

NOTE: Measurement field of view should be 1° - 2°.

6.6. Field of View (FOV) Measurement Method

6.6.1. Luminance measurement method (IEC-63145-20-10:2019)

- ☒2D
- Points
- Moving Points

- ☐Mobile 2D

See "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties" for details. This method is applicable to 2D LMDs or dot LMDs.

measured parameter

- Horizontal field of view
- vertical field of view
- oblique field of view

Note: Judged by a decrease in brightness to 50%.

6.6.2. Michelson contrast measurement method (IEC-63145-20-20:2019)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☐Mobile 2D

See "IEC 63145-20-20:2019 Eyewear display - Part 20-20: Fundamental measurement methods - Image quality" for details. This method applies to 2D LMDs.

measured parameter

- Horizontal field of view
- vertical field of view
- oblique field of view

Note: Judged on Michelson contrast reduction to a specific value.

6.6.3. NED Field-of-view measurement (ICDM)

- ☒2D

- Points
- Moving Points
- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- luminance
- perspectives

NOTE: The evaluation should be performed within plus or minus 1° of the LMD optical axis.

6.6.4. Luminance measurement method (ICDM)

- ☒2D
- Points
- Moving Points
- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- luminance
- perspectives

Remarks: Judged by a decrease in brightness to a given limit (e.g. 50%).

6.6.5. Michelson Contrast Measurement (ICDM)

- ☒2D
- ☐ Point

- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMDs.

measured parameter

- perspectives
- Michelson Contrast

Note: Judged on Michelson contrast reduction to a given limit (e.g., 50%).

6.7. Eye Box Measurement

6.7.1. Luminance measurement method (IEC-63145-20-10:2019)

- ☒2D
- Points
- Moving Points
- ☒Mobile 2D

See "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties" for details. This method is applicable to 2D LMDs and point LMDs.

measured parameter

- height
- high degree
- (of a speech etc) profundity
- volumetric

Remarks: The brightness decreases to a given value as a criterion for judging.

6.7.2. Michelson contrast measurement method (IEC-63145-20-20:2019)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "IEC 63145-20-20:2019 Eyewear display - Part 20-20: Fundamental measurement methods - Image quality" for details. This method applies to 2D LMDs.

measured parameter

- height
- high degree
- (geometry) a diagonal

Note: Judged by Michelson contrast drop to a given value.

6.7.3. Center Luminance Method (ICDM)

- ☒2D
- Points
- ☒ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- luminance
- x, y distance

Remarks: The brightness decreases to a given value as a criterion for judging.

6.7.4. Michelson Contrast Measurement (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMDs.

measured parameter

- Michelson Contrast
- x, y distance

Note: Judged on Michelson contrast reduction to a given value.

6.7.5. Draper method (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMDs.

measured parameter

- Michelson Contrast
- x, y distance

Note: Michelson contrast reduction to a given value is used as a criterion, and this method requires a smaller number of images.

6.7.6. Luminance-based field-of-view method (ICDM)

- ☒2D
- Points
- Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- x, y distance

Remarks: The brightness decreases to a given value as a criterion for judging.

6.7.7. Michelson contrast-based field-of-view method (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMDs.

measured parameter

- x, y distance

Note: Judged by Michelson contrast drop to a given value.

6.8. Aberration Measurement Methods

6.8.1. Standardized distortion measurements (IEC-63145-20-20:2019)

- ☒2D
- Points
- Moving Points
- ☐Mobile 2D

See "IEC 63145-20-20:2019 Eyewear display - Part 20-20: Fundamental measurement methods - Image quality" for details. This method applies to 2D LMDs or dot LMDs.

measured parameter

- distortion

6.8.2. NED Localized Geometric Distortion Measurement (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMDs.

measured parameter

- Percentage of distortion

6.9. Color Alignment Error Measurement Method

6.9.1. Color matching error standard measurements (IEC-63145-20-20:2019)

- ☒2D

- Points
- Moving Points
- ☐Mobile 2D

See "IEC 63145-20-20:2019 Eyewear display - Part 20-20: Fundamental measurement methods - Image quality" for details. This method applies to 2D LMDs or dot LMDs.

measured parameter

- registration error

6.10.Michelson Contrast Measurement Method

6.10.1. Standard Michelson contrast measurement (IEC-63145-20-20:2019)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☐Mobile 2D

See "IEC 63145-20-20:2019 Eyewear display - Part 20-20: Fundamental measurement methods - Image quality" for details. This method applies to 2D LMDs.

measured parameter

- Michelson Contrast

6.10.2. Michelson Contrast Uniformity Measurement (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points

- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMDs.

measured parameter

- Michelson Contrast

6.11. Focal length and Virtual Image Distance (VID) measurements

6.11.1. Focal length method (IEC-63145-20-20:2019)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "IEC 63145-20-20:2019 Eyewear display - Part 20-20: Fundamental measurement methods - Image quality" for details. This method applies to 2D LMDs.

measured parameter

- Michelson Contrast

Note: It is necessary to change the focus of the LMD when measuring.

6.11.2. Parallax method (IEC-63145-20-20:2019)

- ☒2D
- Points
- ☐ Moving Points
- ☒Mobile 2D

See "IEC 63145-20-20:2019 Eyewear display - Part 20-20: Fundamental measurement methods - Image quality" for details. This method applies to 2D LMDs.

measured parameter

- Angle change in two positions

6.11.3. Virtual Image Distance (K. Guo 2019)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☐Mobile 2D

For details, see "Single shot scan less method for virtual image distance measurement for near eye display systems". This method generates two images with a special aperture.

6.11.4. Virtual Image Distance Measurement: Using LMD Lens Focus (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMDs.

measured parameter

- Michelson Contrast

Note: It is necessary to change the focus of the LMD when measuring.

6.11.5. Virtual image distance in field of view (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☒Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method applies to 2D LMDs with focusing lenses.

measured parameter

- Image Focus

Note: It is necessary to change the focus of the LMD when measuring.

6.12. Modulation Transfer Function (MTF)

6.12.1. Space measurements (ICDM)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMDs.

measured parameter

- Michelson Contrast
- Beveled Edge MTF
- resolution (of a photo)

6.13.Black/White Contrast Measurement

6.13.1. Signal contrast ratio (ICDM)

- ☒2D
- Points
- ☐ Moving Points
- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- Black/White Contrast

6.13.2. Crosstalk (ICDM) for dual-view autostereoscopic systems

- ☒2D
- Points
- ☐ Moving Points
- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- Black/White Contrast

6.14.Gamma measurement

6.14.1. Gamma and Gray Scale Distortion (ICDM)

- ☒2D
- Points
- ☐ Moving Points
- ☐Mobile 2D

See "ICDM - Information Display Measurements Standard-V1.1a, 2022" for details. This method is applicable to 2D LMD or dot LMD.

measured parameter

- gamma (Greek letter Γγ) (loanword)
- grayscale

6.14.2. Gamma measurement (DFF)

- ☒2D
- Points
- ☐ Moving Points
- ☐Mobile 2D

For details, see "DFF Display Measurement Specification (DMS) for Automotive-TFT LCDs (V5.1, 2018) (Gamma)". This method is applicable to 2D LMD or dot LMD.

measured parameter

- gamma (Greek letter Γγ) (loanword)
- grayscale

6.15.Pixel angular density measurement

6.15.1. Pixel angular density (IEC-63145-20-10:2019)

- ☒2D
- ☐ Point
- ☐ Moving Points
- ☐Mobile 2D

In "IEC 63145-20-10:2019 Eyewear display - Part 20-10: Fundamental measurement methods - Optical properties" the measurement of pixel angular density is discussed. measurement methods, which includes two main techniques:

- **Basic method**: This method involves counting the number of pixels on a display device (DUT) in a given measurement field. This is typically done by placing a grid or dot matrix on the display surface of the DUT and using image analysis software to determine how many pixels are displayed by the DUT. This method is simple and straightforward, but can be affected by the resolution of the DUT, the accuracy of the measurement device, and environmental factors.
- **Spot Pattern Method**: This method involves activating a certain number of pixels of the DUT, e.g. by displaying a specific spot pattern on the DUT. The stereo angle covered by these activated pixels is then measured. The stereo angle is the angle between one point and another (usually the viewpoint) in 3D space, which describes the number of pixels that are visible at a particular viewing angle. This method provides a more accurate measurement of pixel angular density because it takes into account the actual distribution of pixels and the effects of viewing angle.

measured parameter

- Pixel angular density (PAD), i.e., pixels per degree (PPD) associated with the display device (DUT)

6.16. Test Method Overview

#	Test Methods	2D	point (in space or time)	moving point	Mobile 2D

1	Eye point alignment (ICDM)	☒	☒	☒	☒
2	Eye point alignment using crosshairs (ICDM)	☒	☐	☐	☒
3	Eye point alignment using center brightness (ICDM)	☒	☒	☒	☒
4	Eye point alignment using center resolution (ICDM)	☒	☐	☐	☒
5	Eye point alignment using field of view (ICDM)	☒	☐	☐	☒
6	Centering of NED eyeboxes using lateral chromatic aberration (ICDM)	☒	☐	☐	☒
7	Centering of NED eye boxes using coma, astigmatism, and field curvature (ICDM)	☒	☐	☐	☒
8	Eye-point alignment using the full-field-of-view luminance method (IEC-63145-20-10:2019)	☒	☐	☐	☒
9	Eye point alignment using the Michelson contrast method (IEC-63145-20-10:2019)	☒	☐	☐	☒
10	Luminance measurement (IEC-63145-20-10:2019)	☒	☒	☒	☐
11	Luminance and contrast uniformity measurement (ICDM)	☒	☒	☒	☐
12	Chromaticity and color gamut measurements (IEC-63145-20-10:2019)	☒	☒	☒	☐
13	Chromaticity Color Gamut Area Uniformity Measurement (ICDM)	☒	☒	☒	☐
14	Measurement of colorimetric homogeneity (IEC-63145-20-10:2019)	☒	☒	☒	☐
15	Colorimetric uniformity measurement (ICDM)	☒	☒	☒	☐
16	Contrast measurement (IEC-63145-20-10:2019)	☒	☒	☒	☐
17	Measuring Contrast in Tessellated Patterns Using Large Field of View LMDs (ICDM)	☒	☐	☐	☐

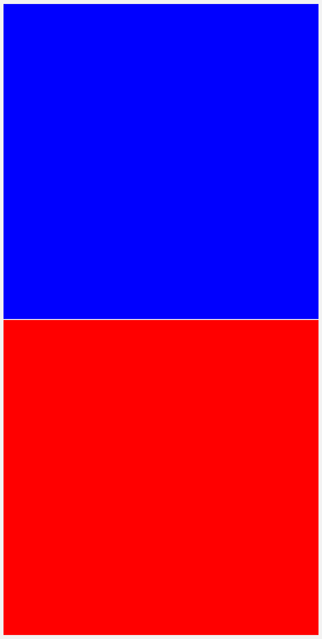
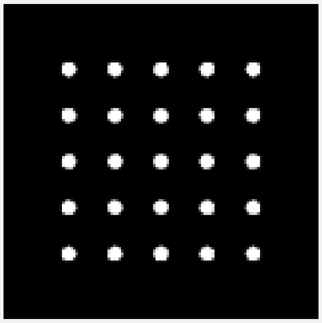
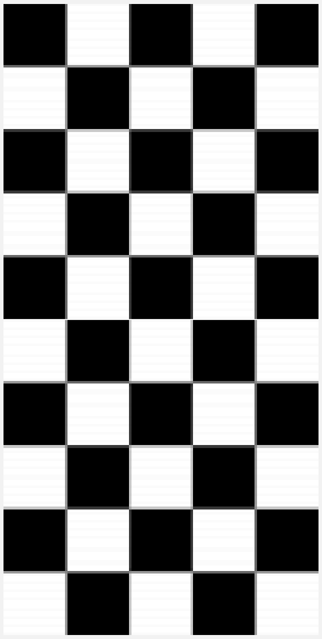
18	Measuring Contrast in Tessellated Patterns Using Small Field of View LMDs (ICDM)	☒	☒	☒	☒
19	FOV luminance measurement method (IEC-63145-20-10:2019)	☒	☒	☒	☐
20	FOV Michelson contrast measurement method (IEC-63145-20-20:2019)	☒	☐	☐	☐
21	NED Field-of-view measurement (ICDM)	☒	☒	☒	☐
22	FOV luminance measurement (ICDM)	☒	☒	☒	☐
23	FOV Michelson Contrast Measurement (ICDM)	☒	☐	☐	☐
24	Brightness measurement method for eye boxes (IEC-63145-20-10:2019)	☒	☒	☒	☒
25	Michelson Contrast Measurement Method for Eye Boxes (IEC-63145-20-20:2019)	☒	☐	☐	☒
26	Eyebox Center Luminance Method (ICDM)	☒	☒	☒	☒
27	Eye Box Michelson Contrast Measurement (ICDM)	☒	☐	☐	☒
28	Eye Cartridge Draper Method (ICDM)	☒	☐	☐	☒
29	Luminance-based field-of-view method (ICDM) for eye boxes	☒	☒	☒	☒
30	Michelson contrast-based visual field angle method (ICDM) for eye boxes	☒	☐	☐	☒
31	Standardized distortion measurements (IEC-63145-20-20:2019)	☒	☒	☒	☐
32	NED Localized Geometric Distortion Measurement (ICDM)	☒	☐	☐	☐
33	Color matching error standard measurements (IEC-63145-20-20:2019)	☒	☒	☒	☒
34	Standard Michelson contrast measurement (IEC-63145-20-20:2019)	☒	☐	☐	☐

35	Michelson Contrast Uniformity Measurement (ICDM)	☒	☐	☐	☒
36	Focal length measurement (IEC-63145-20-20:2019)	☒	☐	☐	☒
37	Parallax measurement (IEC-63145-20-20:2019)	☒	☒	☐	☒
38	Virtual Image Distance (K. Guo 2019)	☒	☐	☐	☐
39	Virtual Image Distance Measurement: Using LMD Lens Focus (ICDM)	☒	☐	☐	☒
40	Virtual image distance in field of view (ICDM)	☒	☐	☐	☒
41	Space measurements (ICDM)	☒	☐	☐	☐
42	Signal contrast ratio (ICDM)	☒	☒	☐	☐
43	Crosstalk (ICDM) for dual-view autostereoscopic systems	☒	☒	☐	☐
44	Gamma and Gray Scale Distortion (ICDM)	☒	☒	☐	☐
45	Gamma measurement (DFF)	☒	☒	☐	☐
49	Pixel angular density (IEC-63145-20-10:2019)	☒	☐	☐	☐

Table 9 Table 9: Summary of test methods

6.17.Test pattern

#	motifs	typical example

1	Full Solid Pattern: A pattern that exhibits display resolution in a single color (usually white, red, green, or blue).	
2	speckled pattern	
3	checkerboard pattern	

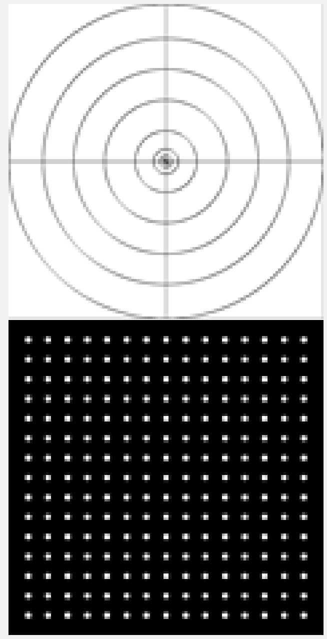
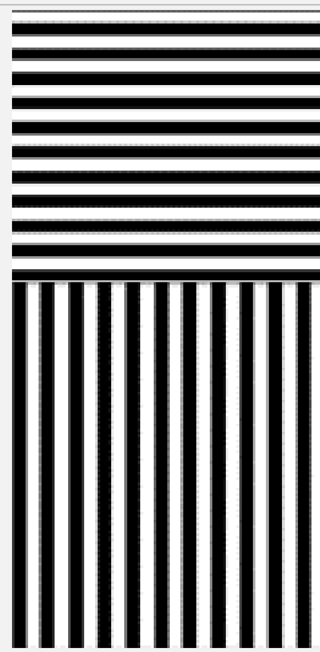
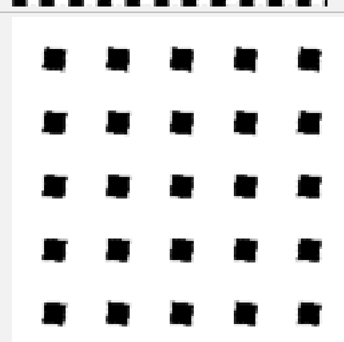
4	registration pattern	
5	Grid Patterns for Michelson Contrast	
6	Tilted Edge Pattern	

Table 10 Table 10: Test Patterns Overview

6.18. Definition of measurement points

In current standards, five or nine measurement points are usually specified in order to accurately assess parameters such as uniformity. The exact location of these measurement points is determined based on the dimensions of the display (see Figure 8). For Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) components or headsets, the measurement points can also be set based on the field of view (FOV), given that the relationship between the display position and the position within the field of view is often not easily determined. Figure 9 provides an example using the FOV as a reference. Considering that there may be differences in the FOV or the shape of the display, the location of the measurement point should be appropriately adjusted to ensure the accuracy and validity of the evaluation results.

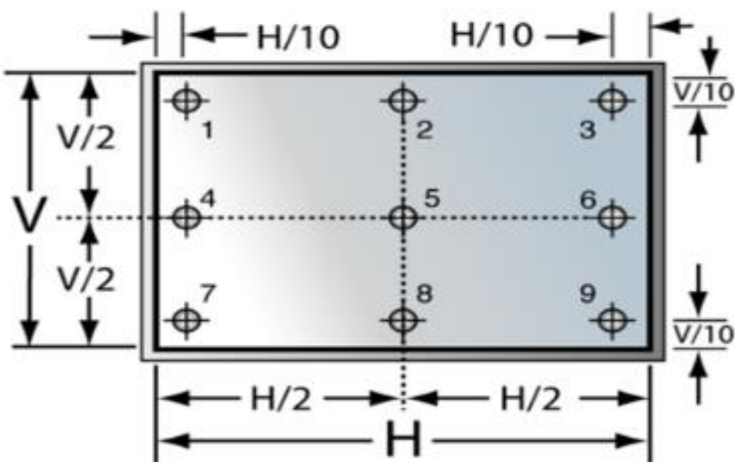


Figure 8 : Example of defining the measurement position using the display dimensions

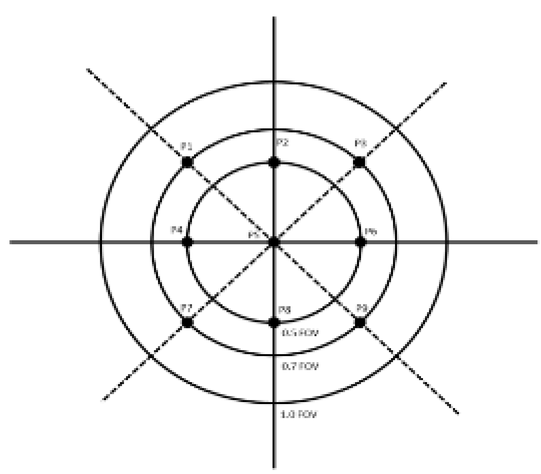


Figure 9 : Defining measurement points in the field of view (FOV) dimensions

7. Measuring platforms

7.1. Measurement settings

The first step in the measurement process is to perform a repeatable calibration. This mainly means finding a starting point which can be used for operations such as eye scanning.ICDM and IEC standards provide a number of calibration procedures. It is also necessary to determine the rotational reference point that should be used in the measurement. One can choose either the pupillary rotation point or the ocular rotation point as the reference for rotation. The eyeball rotation point is more realistic because it simulates the direction of gaze of the human eye (see Figure 10). The eye rotation point is located 10 millimeters behind the pupil point (see Figure 11). Movement of the eyeball results in a noticeable change in the direction of gaze (see Figure 12). For different scenarios of calibration and measurement, see Table 11.

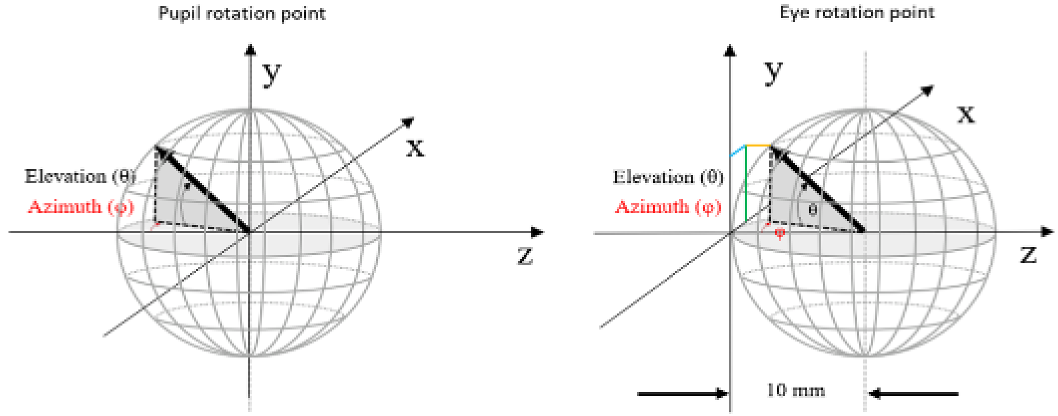


Figure 10 : Different definitions of rotation points

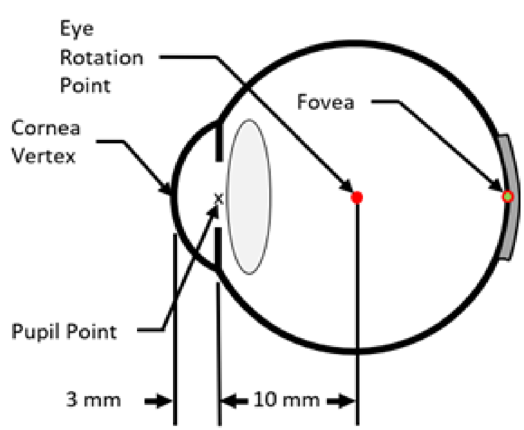


Figure 11 : Geometry of the standard eyeball

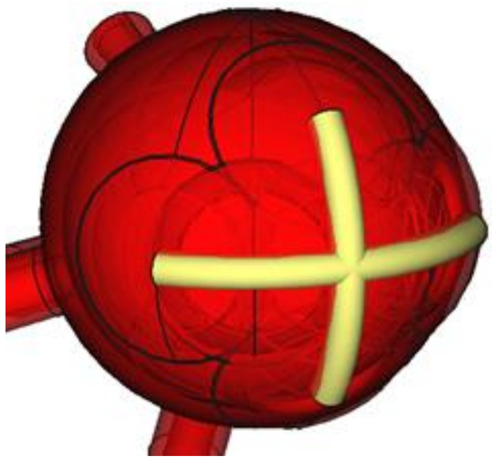


Figure 12 : The yellow area shows the maximum range of rotation of the eye horizontally (50° left and right) and vertically (40° up and down).

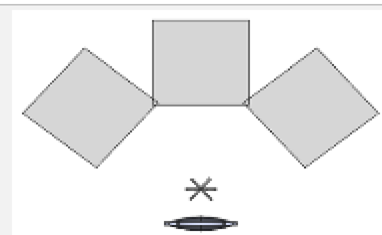
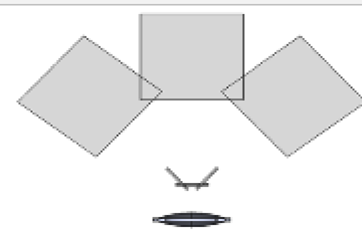
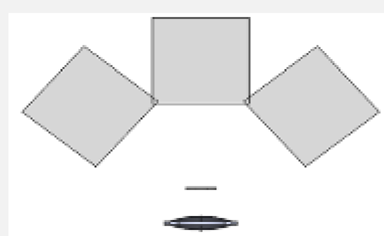
Alignment type	**schema**
Type 1: Pupil fixed to LMD **Rotation point: pupil point** When the LMD is rotated, a different view of the DUT can be seen and the measurement aperture changes accordingly. Does not reflect natural reality.ICDM recommends this method.	
Type 2: Pupil fixed to LMD **Rotation point: eye movement point** When the LMD is rotated, different viewpoints of the DUT can be seen, and the measurement aperture changes accordingly, reflecting natural reality.IEC recommends this method.	
Type 3: Pupil not fixed to the LMD **Point of rotation: pupil point** When the LMD is rotated, a different view of the DUT can be seen while the measurement aperture remains constant. Maintaining a non-tilted view of the DUT is critical when using a 2D photometric device in comparison to a point photometric device.	

Table 11 : Different types of LMD and field of view combinations (note: gray boxes represent LMDs, lenses represent DUTs, and the thin lines between represent fields of view or apertures)

7.1.1. Measuring machine platforms

To ensure consistent and reproducible measurement conditions, the point light measurement device and the 2D light measurement device should be set up similarly to ensure comparable measurement results. One of the key points is the correct alignment of the device under test (DUT) with the light measurement device (LMD).

According to the recommendations of the IEC standard, the setup should fulfill the following accuracy requirements:

- Accuracy < 0.05 mm for x, y, z-axis
- Accuracy of α (tilt angle), Ψ (azimuth) < 0.1°

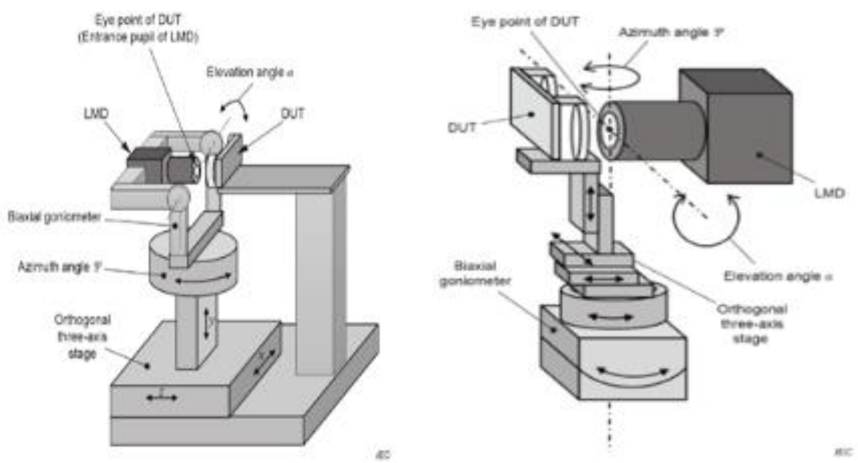


Figure 13 : Basic device configuration based on IEC standards.

Possible solutions include:

- Goniometers with translating and rotating stages (see Figure 14)
- Six-axis motion control system
- robot arm

Mechanisms typically consist of multiple moving elements, as shown in the diagram below. Ensuring that the coordinate systems of all elements are aligned with each other is critical to achieving accurate and reliable movement.

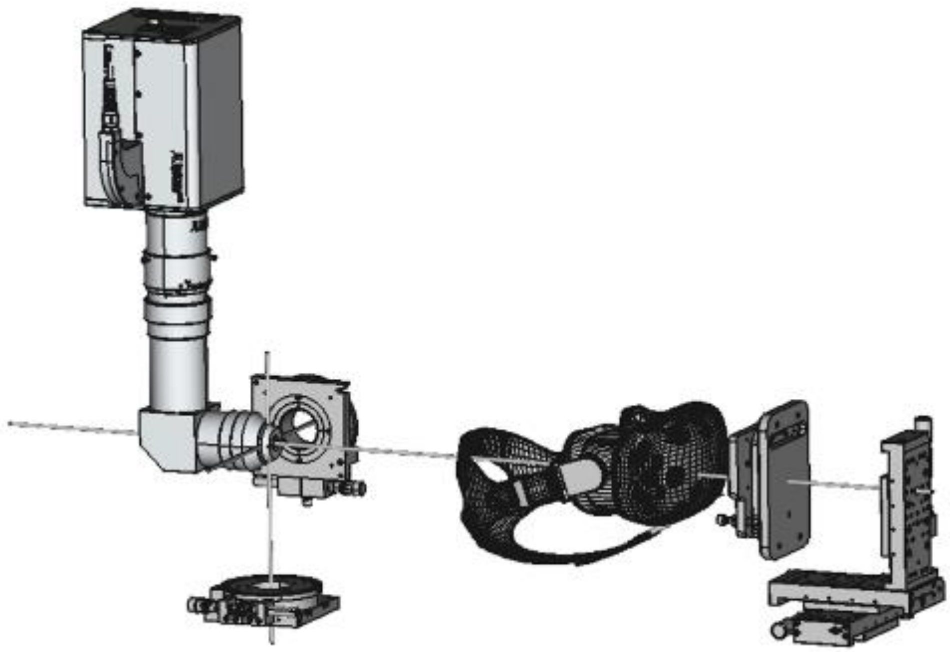


Figure 14 : General view of the required device (exploded schematic)

7.2. alignment process

7.2.1. Preliminary

Before aligning the device under test (DUT) with the measurement device, it is important to ensure that the optical axis of the light measurement device (LMD) is precisely aligned with the mechanical translation table. For example, a laser beam can be passed through the optical fiber of the optical measuring device to check that the optical axis of the LMD is parallel to the rail system. Alternatively, a mirror can be mounted on the XYZ rail system to reflect the laser light back to the 2D optical measuring device. This ensures that other mounts, such as the translation table, are already well aligned with the 2D light measurement device.

The goal of alignment is to align the coordinate system of the Light Measuring Device (LMD) with the coordinate system of the Device Under Test (DUT) so that their axes coincide. Figure 15 clearly shows the goal of alignment.

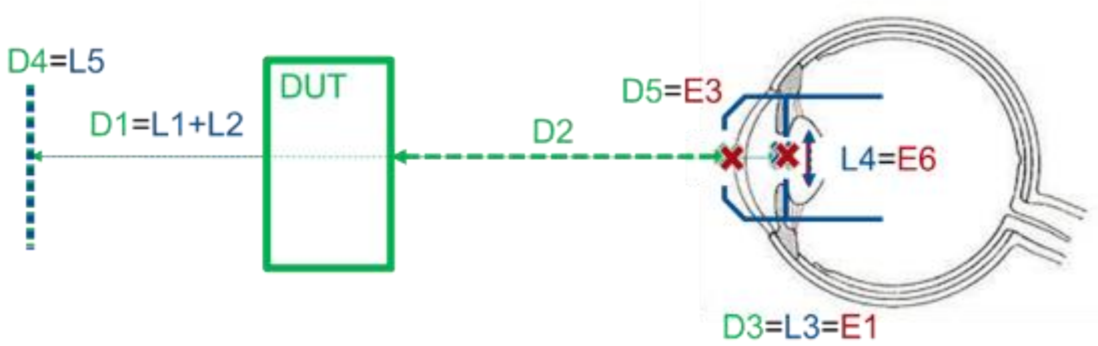


Figure 15 : Aligned coordinate system for LMD and DUT

7.2.2. Crosshair alignment

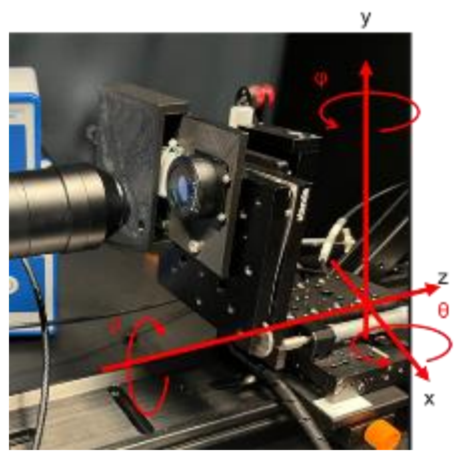


Figure 16 : Crosshair Alignment Test Stage

The following geometric parameters are key factors to focus on during the alignment process:

- φ Azimuth: Controls the rotation of the device in the horizontal plane.
- θ Elevation: Controls the rotation of the device in the vertical plane.
- ρ Rotation: involves the rotation of the device about its own axis.
- z-axis: Used to adjust the eye distance, i.e. the distance between the device and the observer's eyes.
- x, y or other Cartesian coordinates: used to adjust the position of the device in the horizontal plane.

Ideally, the optical axis of an AR/VR optical measurement device should be parallel to the optical guide to ensure accurate measurements. This alignment process is typically accomplished through laser beam calibration to ensure the accuracy of the optical axis alignment.

If the optical axes of an AR/VR optical measurement device are not precisely aligned, the adjustment of the x, y or z coordinates may inevitably affect the adjustment of the other coordinates. This interdependence is particularly important during the alignment process, especially when performing eye-tracking scans, as any small deviation can lead to a decrease in the accuracy of the measurement results.

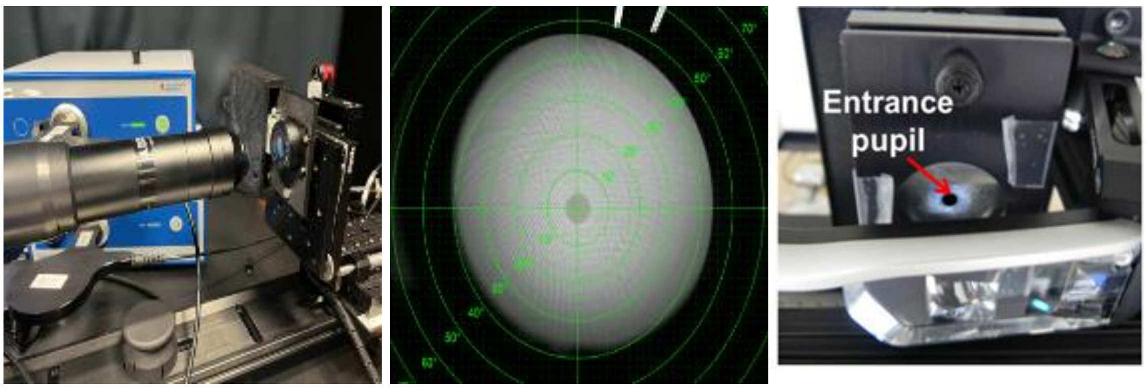


Figure 17 : The crosshair alignment process

Initial Alignment:

Prior to performing the detailed alignment, the DUT first needs to be placed in as accurate a position as possible to ensure a smooth subsequent alignment process. The following are the key steps in the initial alignment:

1. **Center Alignment**: Ensure that the DUT is aligned with the center of the LMD's lens. This is to ensure that the light emitted from the DUT passes correctly through the LMD's lens for accurate measurement results.
2. **Parallel Alignment**: Adjust the DUT so that its surface is parallel to the lens surface of the AR/VR device. Parallel alignment helps reduce image distortion caused by angular deviation and improve alignment accuracy.
3. **Light exposure**: Ensure that the light emitted from the DUT fully illuminates the pupil of the LMD. Correct light exposure is a prerequisite for obtaining clear and accurate measurements and helps to improve the efficiency and accuracy of the entire alignment process.

With the above initial alignment steps, you can lay a good foundation for subsequent fine adjustments, ensuring that the entire alignment process is efficient and precise.

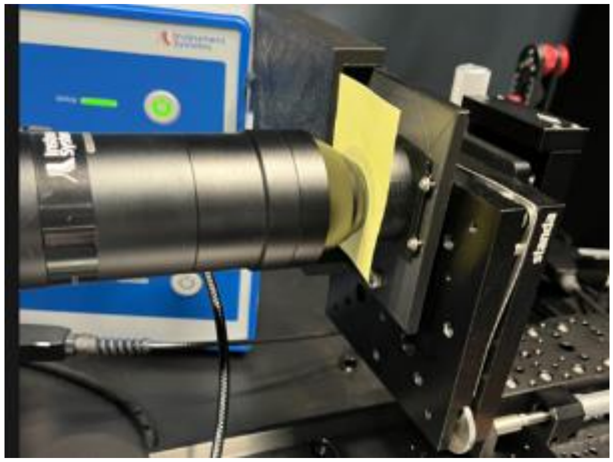


Figure 18 : Z-axis eye alignment process

Z-axis eye alignment:

Eye distance, i.e. the distance between the AR/VR device and the DUT (device to be tested), is one of the key parameters of the DUT. This parameter is usually provided by the device manufacturer. If not explicitly given, 20 mm can be used as the standard default eye distance. The definition of eye distance may vary from standard to standard. One definition treats it as the distance from the surface of the DUT lens to the surface of the eye, while another defines it as the distance from the surface of the lens to the entry pupil of the AR/VR device.

Here are the steps to align the Z-axis eye spacing:

1. Use the Panning Table to move the DUT along the Z-axis, gradually decreasing the distance between the AR/VR lens and the DUT lens.

2. Continue to adjust until the distance between the two is close enough to gently clamp and hold a wobbly piece of paper in place. This step is intended to ensure that no direct contact occurs between the lenses, thus avoiding potential damage.

3. After ensuring that no contact will occur, move the DUT outward along the Z axis until a predetermined eye distance value is reached.

Note: When setting the eye distance, be sure to consider the actual distance between the lens surface and the entry pupil to ensure accurate alignment.

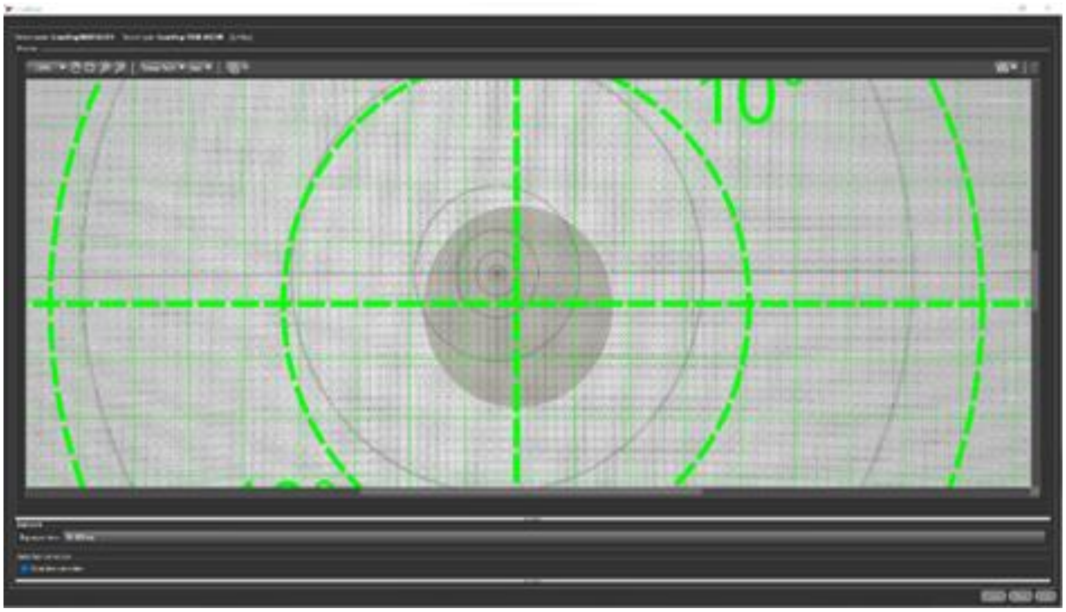


chart 19 : Screenshot of the ρ-axis alignment process

The ρ-axis is aligned:

- Displays the crosshair pattern in the measurement software interface.
- Operate the DUT so that the crosshairs on it align with the crosshairs displayed by the software.
- Fine adjustments are made to ensure that the crosshair axes on the DUT remain parallel to the crosshair axes in the measurement software to achieve a predetermined ρ-axis setting.
- With this alignment, the ρ-axis can be accurately positioned to the specific angle required, ensuring that the axes of the two crosshairs are parallel to each other, thus satisfying the alignment requirements.

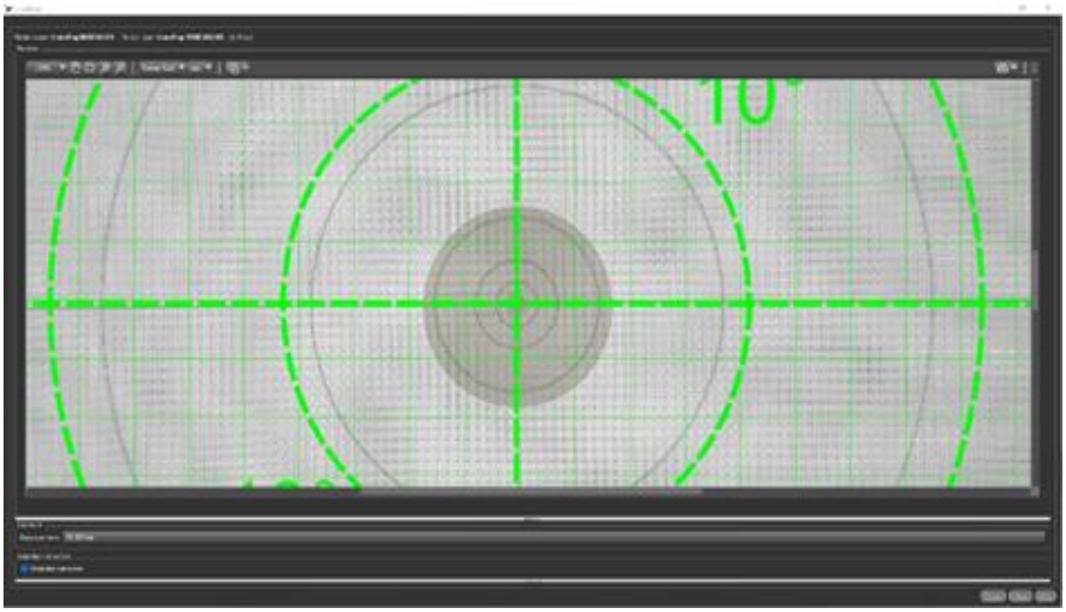


Figure 20 : Screenshot of the φ azimuth/θ elevation alignment process

φ azimuth/θ elevation alignment:

- Project a crosshair pattern on the device under test (DUT).
- Adjust the φ azimuth (horizontal rotation angle) and θ elevation (vertical rotation angle) by rotating the DUT until the center of the crosshair on the DUT is perfectly aligned with the center of the crosshair displayed on the measurement software interface.
- After precise alignment, ensure that the crosshairs are in the same position in both views to complete the alignment of the φ azimuth and θ elevation angles.

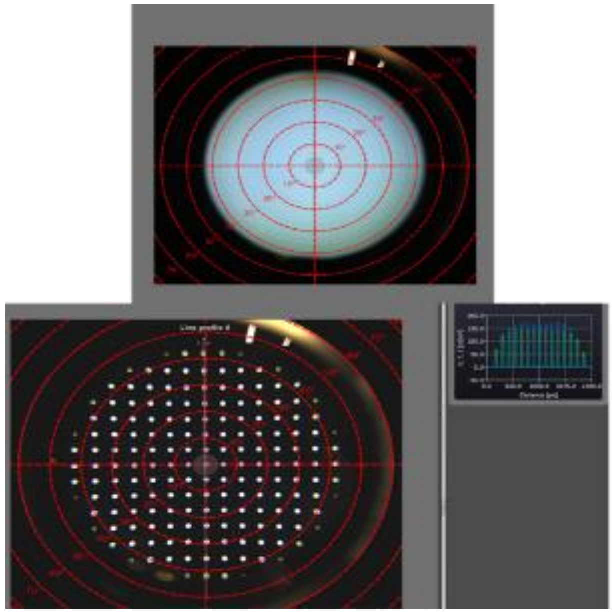


Figure 21 : Screenshot of the X/Y axis alignment process

X/Y axis alignment:

- Alignment of the X/Y axis is achieved primarily by adjusting the luminance values. This process involves gradually adjusting the X/Y coordinates until the luminance peak reaches the center of the field of view and ensures a symmetrical distribution of luminance across the field of view (FOV). For precise alignment, a line function can be applied in the measurement software (setting the line width to cover the entire width of a circular field of view) to ensure that the brightness of points equidistant from the center of the field of view are consistent.
- In addition to relying on luminance values, the alignment process can be aided by other parameters such as contrast, distortion or sharpness.
- After completing the alignment of the X/Y axis, it may be necessary to fine-tune the φ azimuth and θ elevation angles to achieve a more accurate alignment. It should be noted that the adjustment of azimuth and elevation angles may affect the previous X/Y axis alignment status, so the X/Y axis should be rechecked and properly fine-tuned after adjustment to ensure the final alignment accuracy.

7.2.3. Blob Alignment

This section briefly describes a special alignment process. In cases where the z-axis of the DUT is not perfectly aligned with the optical axis and its distance along the z-axis varies within the range of 10 mm to approximately 40 mm, the observed variation in the blobs (spots) will exhibit asymmetry. The following images illustrate both cases of correct and incorrect alignment.

The image on the left shows an example of correct alignment. The top of the image shows the image at the viewpoint, and the bottom shows the image at a position approximately 30 millimeters behind the viewpoint (away from the DUT). The right image, on the other hand, reveals a case of misalignment, again with the image at the top at the viewpoint and the image at the bottom approximately 30 millimeters behind the viewpoint. In the misaligned case, the distribution of spots clearly loses symmetry.

In order to improve the accuracy of the alignment, the alignment process not only needs to take into account the asymmetric variations of the spots, but should also include the adjustment of φ azimuth and θ elevation angles, as well as the precise alignment of the x/y axes. Such a comprehensive adjustment is the key to ensure the alignment accuracy.

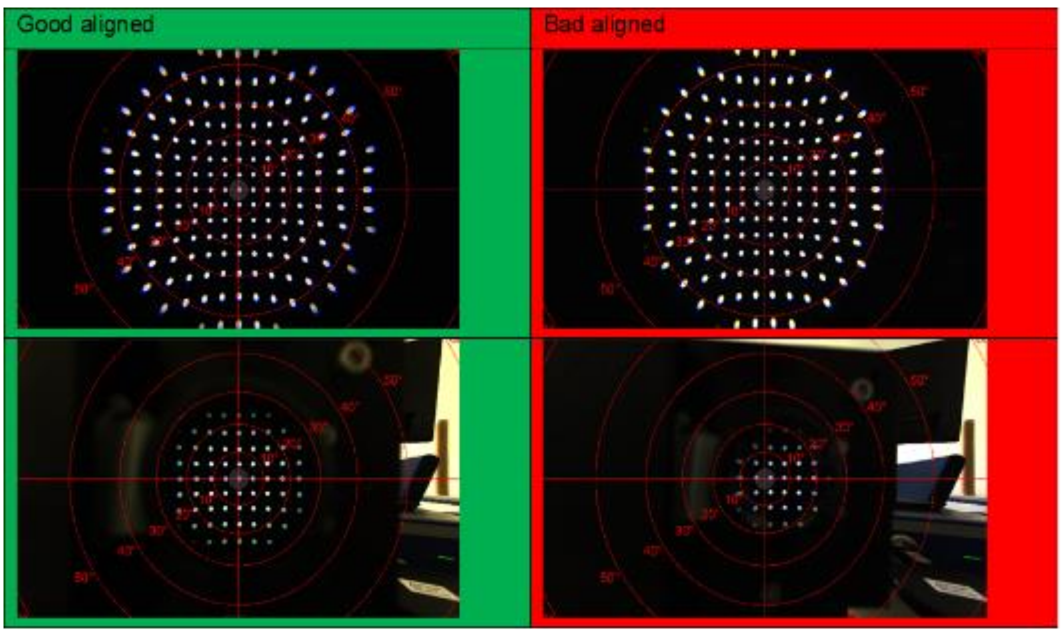


Figure 22 : Spot alignment screenshot, correct (left) vs. incorrect (right)

8. Measurement Example

8.1. Center Virtual Image Basic Measurement:

This section describes methods for making basic measurements of a center virtual image. A center virtual image usually refers to an image that is formed in an optical or display system in a specific way and is located in the center of the optical system. Such images are important for evaluating the performance of an optical system, such as resolution, contrast, and uniformity.

Basic measurements may include an assessment of image brightness and contrast, as well as determining image clarity and stability. These measurements help ensure that the display system delivers high-quality visuals, especially in critical application scenarios such as virtual reality (VR) or augmented reality (AR) systems.

Light Measuring Devices (LMD):

Instrument Systems DMS803 (Goniophotometer).

Device Under Test (DUT):

NED device with Pancake optics and an OLEDonSi display with a resolution of 2560 px x 2560 px.

Test Patterns:

It covers a wide range of colors including pure white, red, green, blue, and black.

Measurement:

First, set the azimuth and elevation angles to 0°, and then place the LMD at viewpoint P5 (refer to the following figure for the exact location).

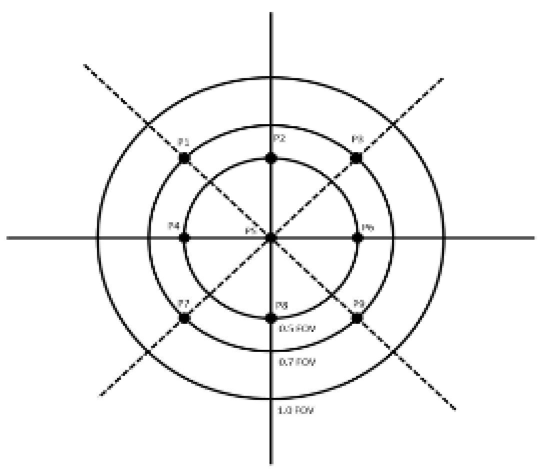


Figure 23 : Defining measurement points in the field of view (FOV) dimensions

Analysis:

The color temperature (CCT) can be calculated from the x,y color coordinates:

$$CCT = 437n^3 + 3601n^2 + 6861n + 5514$$

$$n = \frac{(x - 0.3320)}{(0.1858 - y)}$$

Contrast ratio C_{FWS} can be calculated in the following way:

$$C_{FWS} = \frac{L_w}{L_b}$$

Among them.

- $L_w$is full-frame white brightness.
- L_bIt's full-frame black brightness.

Contrast Ratio C_{FWS} Reflects the degree of difference in the brightness of a screen when displaying pure white and pure black. A high contrast ratio means that the screen is able to display deeper blacks and brighter whites, thus providing a sharper, more vivid image. In optical measurements, a higher contrast ratio usually indicates better performance of the display device.

When calculating the contrast ratio C_{FWS} When calculating the contrast ratio, if you need to take into account the effect of the background brightness behind the screen on the measurement result, you can use the following extended formula:

$$C_{FWS} = \frac{\left(L_w - L_{bg}\right)}{\left(L_b - L_{bg}\right)}$$

Among them.

- $L_w$is full-frame white brightness.
- $L_b$is full-frame black brightness.
- $L_{bg}$is the background brightness (the ambient brightness when the device is turned off).

In practice, if the background brightness has a negligible effect on the measurement results, you can set the L_{bg} set to 0 cd/m². This means that only the brightness and darkness of the screen itself is taken into account when calculating the contrast ratio, regardless of the influence of the external environment.

Measurements:

primary color	**Brightness (cd/m^2)**	**x color coordinates**	**y Color coordinates**	**Color temperature (K)**	**contrast (balance of black and white in TV screen setup)**	**Color gamut coverage**
fig. reactionary	*106.65*	*0.3338*	*0.3589*	5437	>100000	
red (color)	*25.56*	*0.6549*	*0.3345*			88% (DCI-P3)
greener	*66.882*	*0.2468*	*0.6899*			
blue (color)	*10.387*	*0.1746*	*0.0976*			
ferrous	*<0.0001*					

Table Table 12 Table 12: Basic Measurement Reporting Form for ICDM Virtual Image Center (Measurement data in italics and calculation results underlined)

8.2. Uniformity

This section discusses the uniformity of a display system. In optics and display technology, uniformity is the consistency of brightness or color on a display. A display with high uniformity shows the same color or brightness across its entire surface without significant fluctuations in brightness or deviations in color.

Measurement of uniformity typically involves sampling the brightness of different areas of a display and comparing these values to determine if there are significant differences. This is critical to ensuring the quality of the visual experience, especially in applications that require precise color and brightness control, such as professional image editing or medical imaging. Uneven displays can lead to image distortion, affecting user perception and productivity.

Light Measuring Device (LMD):

Instrument Systems LumiTop 5300 ARVR (2D Optical Measurement Equipment)

- Entrance pupil: 3mm
- Focal length: 1000mm

Device Under Test (DUT):

NED device with Pancake optics and TFT-LCD display with 1600 px x 1600 px resolution.

Test Patterns:

Includes full solid white, red, green, blue and black for evaluating the uniformity of the display across colors.

Measurement:

Measurements were taken at 9 different points on the display to assess uniformity across the screen.

measuring point	Field of View (FOV)
P1	0.7 FOV (-0.5 FOV in x and +0.5 FOV in y)
P2	0.5 FOV (0 FOV in x and +0.5 FOV in y)
P3	0.7 FOV (+0.5 FOV in x and +0.5 FOV in y)
P4	0.5 FOV (-0.5 FOV in x and 0 FOV in y)
P5	0 FOV (0 FOV in x and 0 FOV in y)
P6	0.5 FOV (+0.5 FOV in x and 0 FOV in y)
P7	0.7 FOV (-0.5 FOV in x and -0.5 FOV in y)
P8	0.5 FOV (0 FOV in x and -0.5 FOV in y)
P9	0.7 FOV (+0.5 FOV in x and -0.5 FOV in y)

Table 13 Table 13: Measurement points at 9 points

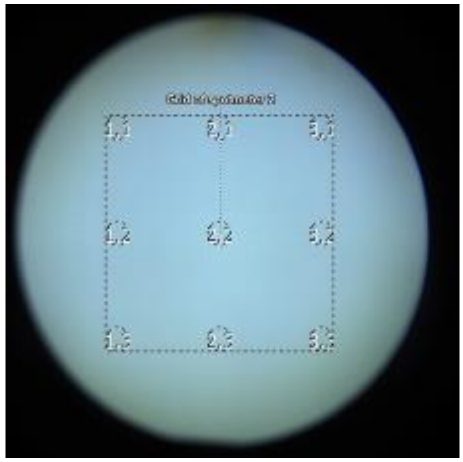


Figure 24 Schematic diagram of 3x3 point measurement

Analysis:

To evaluate the luminance uniformity of a display, we define two key parameters: luminance non-uniformity (NU) and luminance uniformity (U).

Luminance Non-Uniformity NU (N measurement points): This parameter measures the maximum difference in luminance between different measurement points on the display. The formula for calculation is:

$$NU = \frac{L_{vM} - L_{va}}{L_{va}} \times 100\%$$

Among them.

- L_{vM} is the maximum brightness of all measured points, the
- $L_{va}$is the average luminance of all measured points, calculated as.

$$L_{va} = \frac{1}{N}\sum_{i=0}^{N-1} L_{vi}$$

- $L_{vi}$is the measured luminance at the i-th point.

Luminance uniformity U: This parameter indicates the overall uniformity of the display. The calculation formula is:

$$U = 100\% - NU$$

Contrast ratio C_{FWS} can be calculated in the following way:

$$C_{FWS} = \frac{L_w}{L_b}$$

Among them.

- $L_w$is full-frame white brightness.
- L_bIt's full-frame black brightness.

The calculation of the contrast ratio can be extended if it is necessary to take into account the influence of the background brightness on the measurement results:

$$C_{FWS} = \frac{(L_w - L_{bg})}{(L_b - L_{bg})}$$

Among them.

- L_{bg} is the background brightness (the ambient brightness when the device is turned off).

Measurements:

placement	**White brightness (cd/m²)**	**Red brightness (cd/m²)**	**Green brightness (cd/m²)**	**Blue brightness (cd/m²)**	**Black brightness (cd/m²)**	**contrast (balance of black and white in TV screen setup)**
P1	*131.2*	*18.79*	*102.9*	*9.5*	*0.35*	377
P2	*142.5*	*19.99*	*111.7*	*10.7*	*0.34*	418
P3	*131.7*	*18.51*	*103.4*	*9.9*	*0.35*	378
P4	*143.1*	*20.15*	*111.9*	*10.6*	*0.30*	473
P5	*153.9*	*21.31*	*120.6*	*11.3*	*0.33*	467
P6	*144.0*	*20.24*	*112.7*	*10.7*	*0.32*	449
P7	*137.0*	*19.27*	*107.0*	*10.1*	*0.30*	457
P8	*145.3*	*20.40*	*113.4*	*10.9*	*0.31*	476
P9	*133.3*	*18.67*	*104.0*	*9.8*	0.32	419
minimum value	*131.2*	*18.51*	*102.9*	*9.5*	0.30	
maximum values	*153.9*	*21.31*	*120.6*	*11.3*	0.35	
average value	140.2	19.70	109.7	10.4	0.32	

inhomogeneity	10%	8%	10%	9%	8%	
uniformity	90%	92%	90%	91%	92%	

Table Table 14 Table 14: Uniformity Measurement Reporting Form (measurements in italics and calculations underlined)

8.3. contrast (balance of black and white in TV screen setup)

Contrast ratio is an important parameter for measuring the performance of a display device, reflecting the difference in brightness between the brightest and darkest areas on the screen. A display device with a high contrast ratio provides deeper blacks and brighter whites, resulting in a more vivid and clearer image.

Light Measuring Device (LMD):

Instrument Systems LumiTop 5300 ARVR (2D Optical Measurement Equipment)

- Entrance pupil: 3mm
- Focal length: 1000mm

Device Under Test (DUT):

NED device with Pancake optics and TFT-LCD display with 1600 px x 1600 px resolution.

Test Patterns:

The test pattern uses a 5x5 checkerboard pattern.

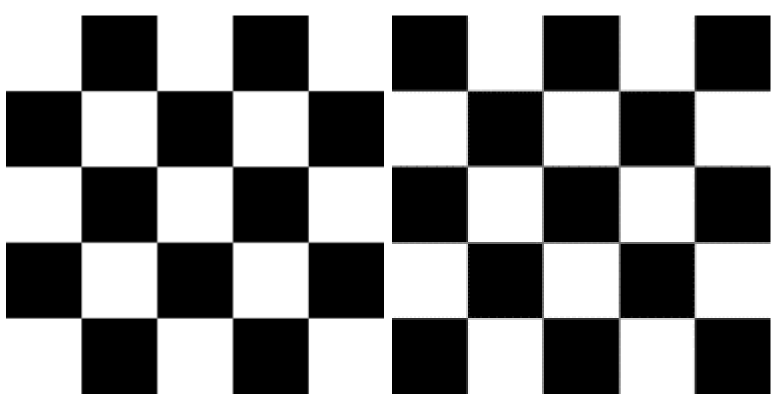


Figure 25 : Contrast measurement test pattern

Measurement:

The 2D photometric device was set up to make measurements using polar coordinates, and two measurements were made: one using a checkerboard pattern centered on white, and the other using a checkerboard pattern centered on black. This measurement method is useful for evaluating the brightness and contrast performance of the monitor when displaying pure white and pure black, as well as the effect of transition between areas of different brightness.

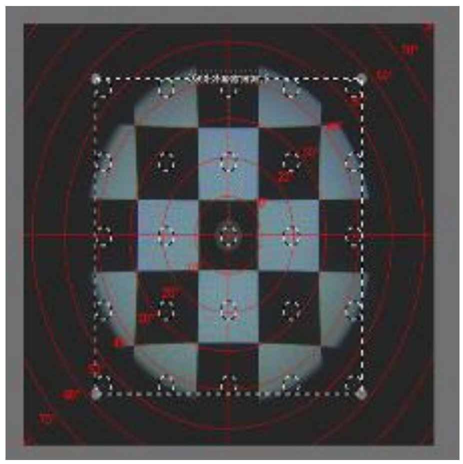


Figure 26 : Contrast example measurements

Analysis:

In the contrast analysis, measurements were taken using only the area within the red box of the checkerboard pattern.

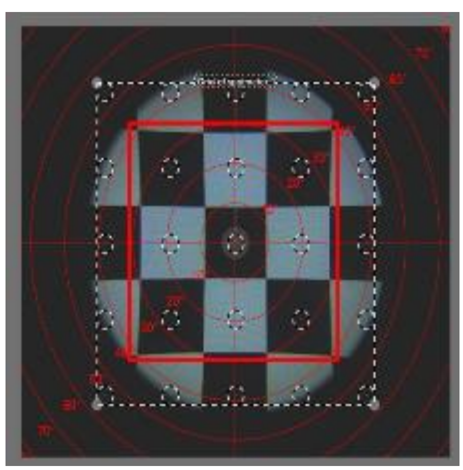


Figure 27 : The red box shows the analyzed area

Measurements:

The measured contrast is summarized in the table below:

65.8	43.3	79.0
58.3	60.7	44.4
56.7	43.5	51.1

Table 15 Table 15: Contrast ratio of labeled 3x3 points

Note: Contrast is affected by the LMD optical system. Contrast may be affected by the characteristics of the LMD optical system during measurement. For example, scattering phenomena within the LMD may alter the measurement results, often resulting in lower contrast values. In order to obtain more accurate measurements, it is possible to characterize the measurement device, i.e. the influence of the measurement device on the result is quantified and subtracted from the final measured value. However, in some cases (e.g. NED devices) this characterization process can be complicated.

The LumiTop ARVR (2D Light Measuring Device) typically measures lower contrast than a DMS (Goniophotometer) when using a checkerboard pattern, a difference that is primarily due to the more significant light scattering in the LumiTop lens.

Contrast ratio (center point, P5) measured with the LumiTop 5300 ARVR	60.7
Contrast ratio (center point, P5) measured with DMS-803	139.2

Table 16 Comparison of LumiTop and DMS Checkerboard Pattern Contrast Ratio

8.4. Aberration Measurement

Accurately measuring the optical aberration of near-eye displays is a critical aspect when manufacturing AR/VR/MR devices. This aberration originates from the characteristics of the lens, so in order to effectively compensate for this phenomenon, the device needs to have accurate information about the aberration that

Note: Aberrations are analyzed using a Cartesian coordinate system.

Light Measuring Device (LMD):

Instrument Systems LumiTop 5300 ARVR (2D Optical Measurement Equipment)

- Entrance pupil: 3mm
- Focal length: 1000mm

Device Under Test (DUT):

NED device with Pancake optics and an OLEDonSi display with a resolution of 2560 px x 2560 px.

Test Patterns:

Aberration measurements were made using a speckle (blob) pattern (see Figure 28).

- 25x25 spots
- Test pattern size 2560 px x 2560 px
- Spot spacing 100 px
- Spot radius 15 px

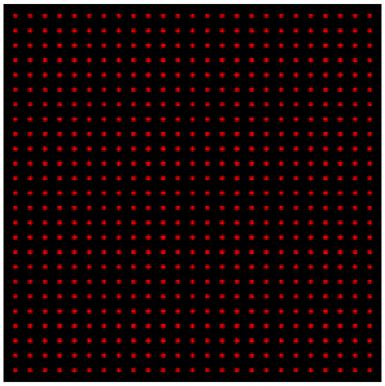


Figure 28 : Speckle pattern for red aberration measurements

Measurement:

FIG. 29 shows an example of lens distortion measurement using a red spot pattern. This measurement determines the degree of lens distortion by analyzing the degree of distortion of the dots in the image.

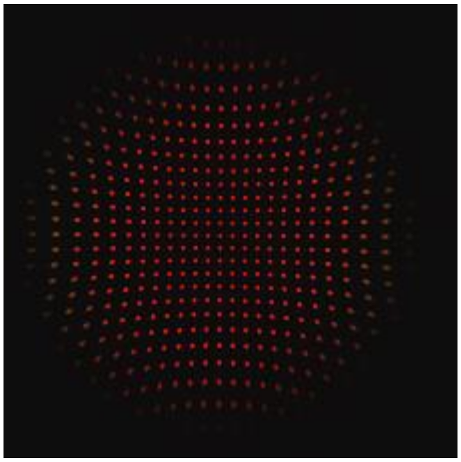


Figure 29 : Example of lens aberration measurements using the red speckle pattern

Analysis:

The main steps of distortion analysis include:

1. Detects the position of the dot.
2. Generate a grid of expected positions using the dots near the center of the image. This step assumes that the distortion of the dots near the center can be ignored.
3. Calculate the degree of distortion for each dot$d_{i,j}$ The degree of distortion of the

$$d_{i,j} = \frac{h'_{i,j} - h_{i,j}}{h_{i,j}}$$

Among them.

- $d_{i,j}$denotes the degree of distortion of the dots with indexes i and j, the
- i and j are the indexes of the dots with respect to the center dot (the center dot is indexed by i=j=0), the
- $h'_{i,j}$is the actual measured distance of the dot indexed i,j with respect to the center.
- $h_{i,j}$is the expected distance of the dots indexed i,j calculated from the grid distance m determined from the distance between the dots at the center of the image, given by.

$$h_{i,j} = \sqrt{(i \times m)^2 + (j \times m)^2}$$

FIG. 27 gives an example of the expected and actual measurement of the location of the dot.

Figure 30 : Expected (blue dots) and actual (red squares) measured dot positions for the red pattern

Measurements of the DUT used showed an aberration of 26.6% (see figure below).

N/M	M=-11	M=-10	M=-9	M=-8	M=-7	M=-6	M=-5	M=-4	M=-3	M=-2	M=-1	M=0	M=1	M=2	M=3	M=4	M=5	M=6	M=7	M=8	M=9	M=10	M=11
N=-11									24,8%	23,5%	22,6%	22,3%	22,6%	23,4%	24,8%								
N=-10							23,4%	21,0%	19,2%	18,0%	17,3%	17,1%	17,3%	18,0%	19,2%	21,0%	23,4%						
N=-9					24,8%	21,2%	18,5%	16,4%	14,8%	13,7%	13,1%	12,9%	13,1%	13,8%	14,8%	16,4%	18,5%	21,3%	24,9%				
N=-8				24,4%	20,2%	17,1%	14,7%	12,8%	11,5%	10,5%	9,9%	8,7%	9,9%	10,4%	11,4%	12,8%	14,5%	17,0%	20,2%	24,3%			
N=-7			25,0%	20,3%	16,7%	13,8%	11,7%	10,0%	8,8%	7,8%	7,3%	7,1%	7,2%	7,7%	8,6%	9,9%	11,6%	13,8%	16,5%	20,2%	24,9%		
N=-6		26,6%	21,4%	17,1%	13,9%	11,3%	9,3%	7,8%	6,6%	5,7%	5,2%	5,0%	5,2%	5,6%	6,4%	7,6%	9,2%	11,2%	13,8%	17,0%	21,2%		
N=-5		23,6%	18,8%	14,7%	11,7%	9,3%	7,4%	6,0%	4,8%	4,0%	3,5%	3,3%	3,5%	3,9%	4,7%	5,8%	7,3%	9,2%	11,8%	14,8%	18,4%	23,4%	
N=-4		21,1%	16,5%	12,8%	10,0%	7,7%	5,9%	4,5%	3,5%	2,7%	2,2%	2,0%	2,1%	2,5%	3,2%	4,3%	5,7%	7,6%	10,0%	12,8%	16,4%	20,9%	
N=-3	25,1%	19,4%	14,9%	11,5%	8,8%	6,9%	4,9%	3,5%	2,4%	1,6%	1,1%	0,9%	1,0%	1,4%	2,1%	3,2%	4,6%	6,4%	8,7%	11,4%	14,9%	19,2%	24,8%
N=-2	23,7%	18,2%	13,9%	10,6%	7,9%	5,9%	4,1%	2,8%	1,7%	0,9%	0,4%	0,1%	0,3%	0,7%	1,4%	2,4%	3,8%	5,6%	7,8%	10,5%	13,8%	18,0%	23,4%
N=-1	22,8%	17,5%	13,3%	10,1%	7,4%	5,4%	3,7%	2,4%	1,3%	0,6%	0,1%	-0,3%	-0,2%	0,2%	0,9%	2,0%	3,3%	5,1%	7,3%	9,9%	13,2%	17,3%	22,6%
N=0	22,9%	17,2%	13,1%	9,9%	7,3%	5,3%	3,6%	2,2%	1,2%	0,5%	0,0%	0,0%	-0,2%	0,0%	0,8%	1,9%	3,2%	4,9%	7,1%	9,7%	13,0%	17,1%	22,4%
N=1	22,8%	17,4%	13,4%	10,1%	7,5%	5,4%	3,7%	2,4%	1,4%	0,7%	0,3%	0,0%	-0,1%	0,3%	1,0%	2,1%	3,4%	5,2%	7,3%	9,5%	13,2%	17,3%	22,8%
N=2	23,7%	18,2%	14,0%	10,7%	8,0%	5,9%	4,2%	2,9%	1,8%	1,2%	0,8%	0,5%	0,5%	0,8%	1,5%	2,6%	3,9%	5,7%	7,8%	10,5%	13,8%	18,1%	23,7%
N=3	25,1%	19,5%	15,0%	11,6%	8,9%	6,7%	4,9%	3,8%	2,5%	1,8%	1,4%	1,1%	1,2%	1,5%	2,3%	3,3%	4,7%	6,5%	8,7%	11,4%	14,9%	19,3%	
N=4		21,3%	16,7%	13,0%	10,1%	7,9%	6,0%	4,6%	3,5%	2,8%	2,3%	2,1%	2,2%	2,6%	3,4%	4,4%	5,9%	7,8%	10,0%	12,6%	16,5%	21,2%	
N=5		23,7%	18,8%	14,9%	11,9%	9,4%	7,5%	6,0%	4,9%	4,2%	3,7%	3,5%	3,6%	4,0%	4,8%	5,9%	7,4%	9,3%	11,7%	14,7%	18,7%	23,0%	
N=6			21,7%	17,4%	14,1%	11,5%	9,5%	7,9%	6,7%	5,9%	5,4%	5,2%	5,3%	5,8%	6,6%	7,8%	9,4%	11,4%	13,8%	17,3%	21,8%		
N=7			25,3%	20,6%	17,0%	14,1%	11,9%	10,2%	8,9%	8,0%	7,5%	7,3%	7,5%	8,0%	8,8%	10,1%	11,8%	13,9%	16,8%	20,6%			
N=8				24,0%	20,6%	17,4%	14,9%	13,0%	11,6%	10,7%	10,1%	9,9%	10,2%	10,7%	11,6%	13,0%	14,9%	17,3%	20,9%				
N=9					25,5%	21,8%	18,9%	16,7%	15,1%	14,1%	13,5%	13,3%	13,5%	14,1%	15,2%	16,7%	18,8%	21,6%					
N=10							24,0%	21,5%	19,7%	18,4%	17,7%	17,5%	17,8%	18,9%	19,7%	21,5%	23,9%						
N=11									25,4%	23,9%	23,1%	22,8%	23,1%	23,9%	25,4%								

Figure 31 : Aberration measurements of the red pattern

8.4.1. Aberration measurement of distorted images

With the results obtained from the aberration measurements, the user can create a model to pre-compensate for the image's aberrations. This method corrects the distortion by adjusting the way the image is displayed. The figure below shows the dot pattern used to pre-compensate for the distortion.

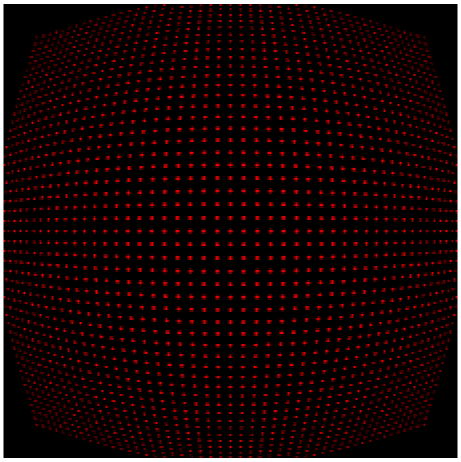


Figure 32 Fig. 32: Pre-compensated dot pattern for the red pattern

After applying the pre-compensation pattern, the visible pattern is shown in Figure 33. This pattern was pre-compensated for aberrations and was able to be displayed more accurately, reducing the image distortion caused by lens aberrations.

Figure 33 : Shows the display image of a NED using a pre-compensated pattern. With the pre-compensated pattern, the distortion of the image is corrected, making the display more realistic and accurate

Images using real photographs, pre-compensated patterns and NED displays are shown separately in FIG. 34, while in FIG. 35 a direct comparison is made between no pre-compensation and the use of a pre-compensated pattern as input.

Figure 34 : left: pre-compensated image; right: image displayed by NED

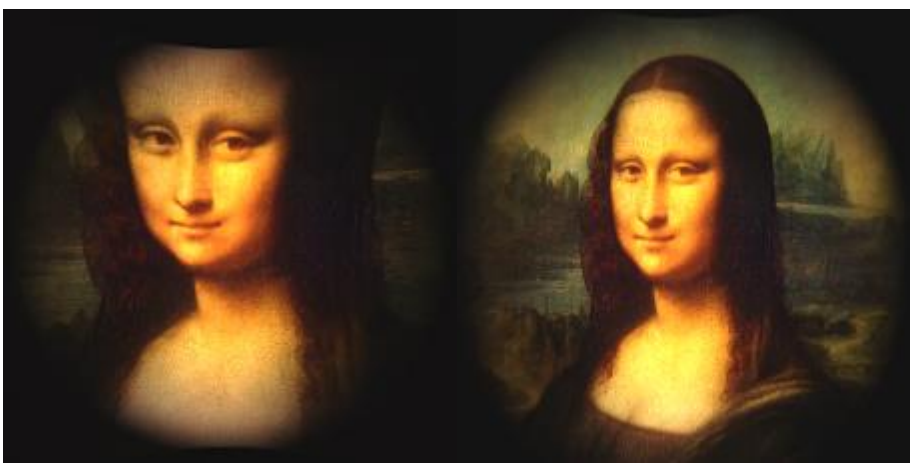


Figure 35 : Left: Displayed image without pre-compensated image; Right: Displayed image with pre-compensated image

8.4.2. Color Difference Measurement

The data recorded during aberration measurements can be used to quantify color differences. This is accomplished by comparing the positions of dots in different color channels (e.g., red, green, and blue). Chromatic aberration results from the difference in the ability of lenses to focus different colors of light, and this difference can result in blurring or haloing at the edges of image colors.

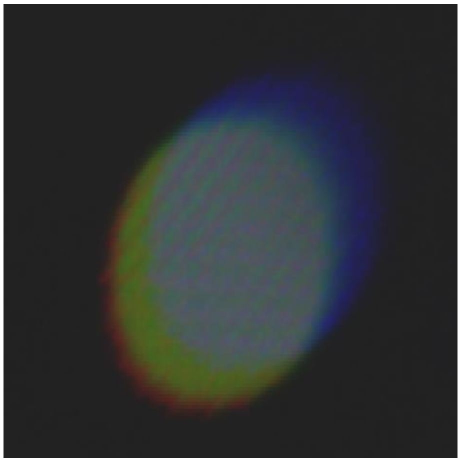


Figure 36 : Shows the dots enlarged using a white dot pattern to show the color difference. Here, the difference in the position of the dots in the different color channels is clearly visible; this difference is the chromatic aberration, which causes blurring or haloing at the edges of the image colors

8.5. Sharpness

8.5.1. Michelson Contrast

Michelson contrast is the same as the contrast transfer function (CFT). In the case of near-eye displays, Michelson contrast is often also referred to as MTF (modulation transfer function).

Light Measuring Devices (LMD):

Instrument Systems LumiTop 5300 ARVR (2D Optical Measurement Equipment)

- Entrance pupil: 3mm
- Focal length: 1000mm

Device Under Test (DUT):

NED device with Pancake optics and TFT-LCD display with 1600 px x 1600 px resolution.

Test Patterns:

The Michelson contrast test pattern is shown below in the illustration:

- Lines consisting of 2 pixels black and 2 pixels white

- Test pattern size 1600 pixels x 1600 pixels
- horizontal alignment

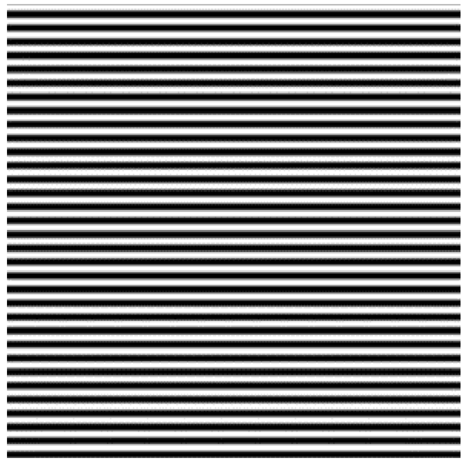


Figure 37 : Test Patterns for Measuring Michelson Contrast

Measurement:

The measurement process utilizes a polar aberration setting. This setting helps to more accurately analyze and correct the distortion of an image, especially in cases where the difference in distortion between the center and edge areas of an image needs to be taken into account.

Analysis:

Michelson Contrast Ratio $C_{m,i}$ can be calculated in the following way:

$$C_{m,i} = \frac{L_{vM,i} - L_{vm,i}}{L_{vM,i} + L_{vm,i}}$$

Among them.

- $C_{m,i}$ denotes the contrast between the pointP_i of Michelson's contrast.
- $L_{vM,i}$ Indicates the maximum brightness in the pointP_i the maximum brightness in the image.
- $L_{vm,i}$ Indicates the minimum brightness in the pointP_i image with minimum brightness.

Tip: Most optical measurement device systems are not diffraction-limited designs, which means that it cannot be used to measure absolute Michelson contrast values for optical systems (e.g. NEDs). However, as long as the Michelson contrast value is not too low (i.e., the spatial frequency is not too high, >0.2 or 20%), comparisons between DUTs can be made. Such comparisons are useful for assessing performance differences between devices.

8.5.2. Beveled edge analysis

Beveled edge analysis is a method used to measure image sharpness, although it is not specifically defined for measuring NEDs. The advantage of using the slant-edge analysis is that it provides the spatial frequency response (SFR) over the full spatial frequency range.

Light Measuring Devices (LMD):

Instrument Systems LumiTop 5300 ARVR (2D Light Measurement Equipment)

- Entrance pupil: 3mm
- Focal length: 1000mm

Device Under Test (DUT):

NED device with Pancake optics and TFT-LCD display with 1600 px x 1600 px resolution.

Test Patterns:

The test pattern for the beveled edges is shown below in the exhibit:

- Consists of 11x11 squares
- Test pattern size 1600 pixels x 1600 pixels
- Distance between squares is 100 pixels
- Each square is 50 pixels in size

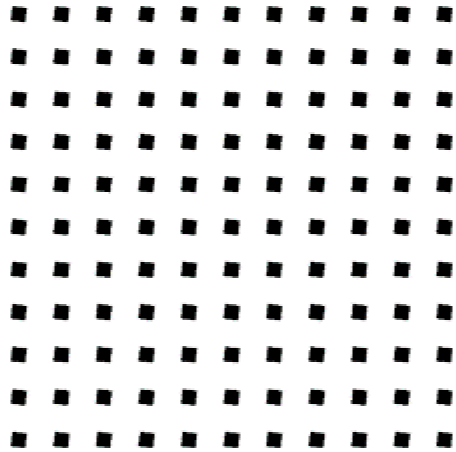


Figure 38 : Test pattern for measuring beveled edges

Measurement:

The measurement process utilizes a polar distortion setting that converts the units of measurement from cycles per pixel (cyc/px) to cycles per degree (cyc/°). This conversion helps to more accurately assess the performance of an image at different viewing angles, especially when it is necessary to consider how the image will appear over a wide range of viewing angles.

Analysis:

The cycle per pixel (cyc/px) is a unit of spatial frequency that corresponds to the pixels in the image. To transform this unit into a more intuitive unit, such as cycles per degree (cyc/°), it is recommended to use the polar coordinate setting as a de-distortion method, so that an image with angular coordinates can be acquired directly. By applying a conversion factor from pixels to degrees, spatial frequencies can be converted according to the following relationship:

This conversion helps to convert spatial frequency measurements from pixel units to angular units for a more intuitive assessment of image performance at different viewing angles.

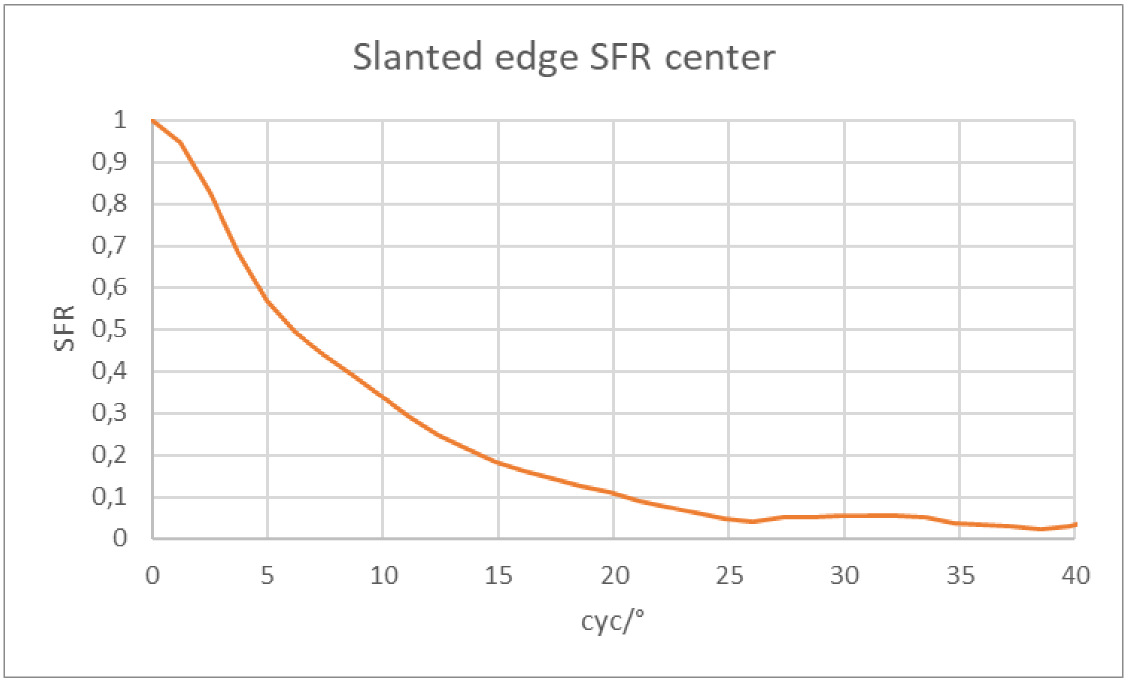


Figure 39 : The data have been converted to cycles per degree (cyc/°) to facilitate a more intuitive understanding and use of the data.

Tip: Most optical measurement equipment systems are not diffraction-limited designs, which means that it cannot be used to measure absolute spatial frequency response (SFR) values for optical systems such as NEDs. However, as long as the SFR value is not too low (i.e., the spatial frequency is not too high, >0.2 or 20%), comparisons between DUTs can be made. Such comparisons are useful for evaluating performance differences between devices.

8.6. Virtual Image Distance Measurement (2D Optical Measurement Equipment)

Utilizing 2D optical measuring devices or point source measurement techniques, we are able to accurately measure the distance of a virtual image. The following example demonstrates how a measurement can be made using parallax method using a 2D optical measurement device. This technique requires the collection of at least two data points for an accurate assessment.

Light Measuring Devices (LMD):

Instrument Systems LumiTop 5300 ARVR (2D Light Measurement Equipment)

- Entrance pupil: 3mm

- Focal length: 1000mm

Device Under Test (DUT):

- NED device with Pancake optics and an OLEDonSi display with a resolution of 2560 px x 2560 px.
- NED allows the diopter setting to be adjusted from +1 dpt to -5 dpt.

Test Patterns:

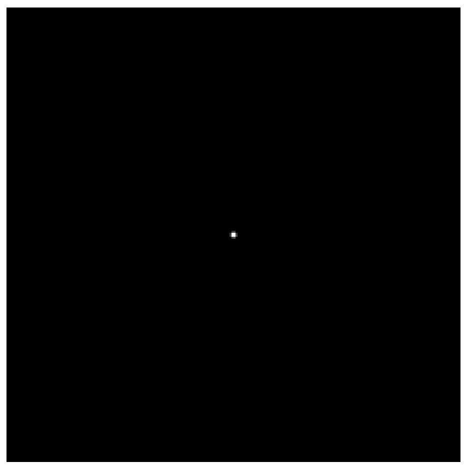


Figure 40 : Virtual image distance measurement using a single dot pattern

Measurement:

In order to perform a measurement, the device under test (DUT) or light measurement device (LMD) must be moved a specific distance in the x- or y-axis direction relative to the position of the human eye. The following is the measurement process:

1. Move the device 3 mm to the left along the x-axis from the human eye position.
2. Capture the image at this new location.
3. Subsequently, the device was moved 3 mm to the right along the x-axis from the human eye position.
4. Capture the image again.

A polar coordinate system is used for the measurement process, which facilitates direct angular measurements.

Analysis:

The diopter and its range are calculated by the reciprocal of the obtained focal length range:

$$D_0 = \frac{1}{\gamma_o}$$

Among them.

$D_o$represents the refractive error at the P0 (center) point, the

$\gamma_o$represents the focal length (in meters) at point P0 (center).

8.7. Virtual Image Distance Measurement (Spot Light Measurement Equipment)

Light Measuring Devices (LMD):

Instrument Systems DMS803 (Goniophotometer).

Device Under Test (DUT):

NED device with Pancake optics and an OLEDonSi display with a resolution of 2560 px x 2560 px.

Test Patterns:

Use the crosshair pattern.

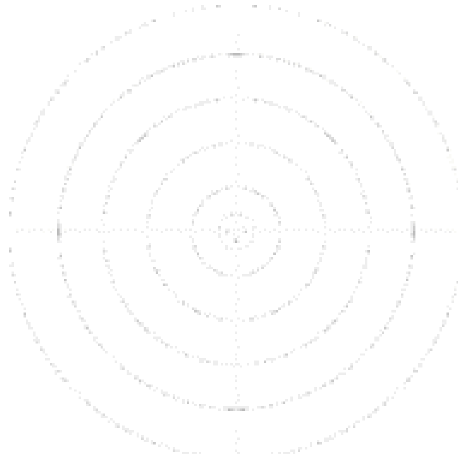


Figure 41 : Crosshair pattern for virtual image distance measurement

Measurement:

- The crosshair pattern is accurately aligned to the center of the viewfinder by the angle adjustment device of the goniophotometer, and the current angle value is recorded.
- Move the device 3 mm to the right along the x-axis from the human eye position.
- Using the angle adjustment device of the goniophotometer again, re-align the crosshair pattern to the center of the viewfinder and record the new angle value.

NOTE: The goniophotometer system has been configured to respond only to changes in the φ angle, so movement along the x-axis will directly result in a change in the φ angle.

x-axis position (mm)	φ angle (°)
-3	-0.64
3	0.71

Table 17 Table 17: Measurement results of φ angle

Analysis:

The virtual image distance is derived by calculating the displacement between two points and the measured angle.

$$VID_m = \frac{\Delta x}{tan(\Omega)}$$

Measured value W	1.35° = 0.71° - (-0.64°)
Δx (change in position)	6 mm
MeasuredVID_m (m)	0.254
DUT expectedVID_m (m)	0.25

Table 18 : Virtual Image Distance Measurement Results

8.8. field of view measurement

Light Measuring Devices (LMD).

Instrument Systems LumiTop 5300 ARVR (2D Light Measurement Equipment)

- Entrance pupil: 3mm
- Focal length: 1000mm

Device Under Test (DUT).

NED device with Pancake optics and an OLEDonSi display with a resolution of 2560 px x 2560 px.

Test Patterns:

Use a solid white pattern.

Measurement:

The measured image is shown below.

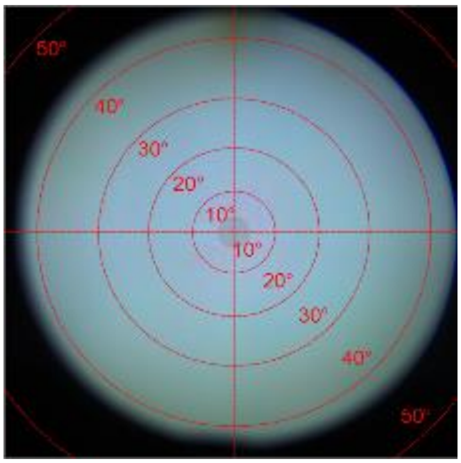


Figure 42 : Measured image of the white pattern

Analysis:

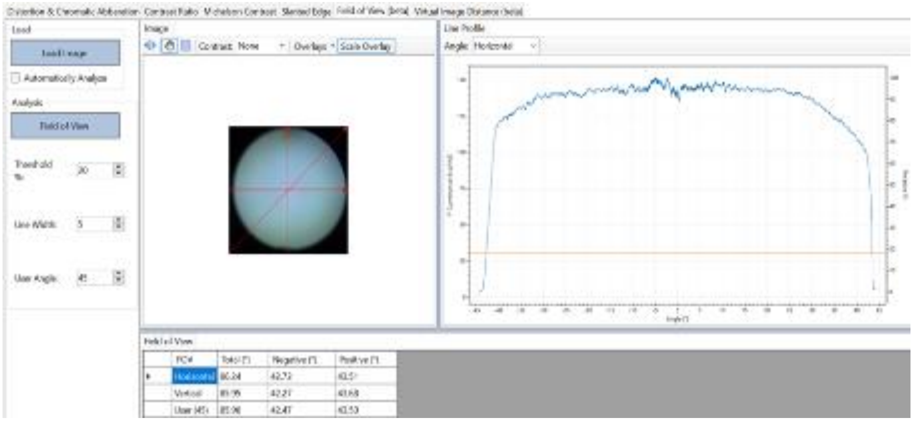


Figure 43 Screenshot of field-of-view analysis

The results of the analysis are summarized in Table 19 (luminance threshold is 20% of the center luminance).

field of view	Total (°)	Negative (°)	Positive (°)
level (of achievement etc)	86.24	42.72	43.51
perpendicular	85.95	42.27	43.68
User (45°)	85.96	42.47	43.50

a meter (measuring sth) 19 : Results of the field of view analysis

8.9. Eye box measurements

Light Measuring Device (LMD):

Instrument Systems DMS803 (Goniophotometer).

Device Under Test (DUT):

NED device with Pancake optics and an OLEDonSi display with a resolution of 2560 px x 2560 px.

Test Patterns:

Use a solid white pattern.

Measurement:

Measurements were made under reference conditions of θ = 0° and φ = 0°, with the measurement ranges set from -15 mm to 15 mm for the x-axis, as well as from -15 mm to 15 mm for the y-axis.

Analysis:

Judged by a decrease in brightness to 50% of the center brightness.

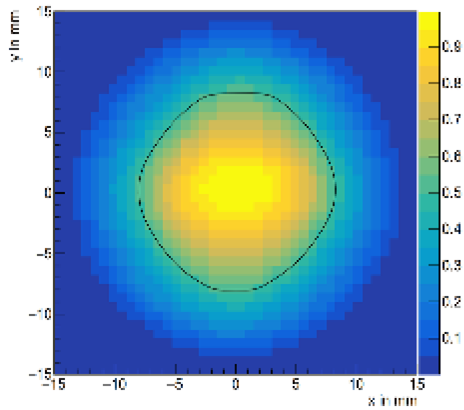


Figure 44 : Scan of the eye box at an eye distance of 12 mm. The figure illustrates the relative luminance distribution. The black line marks the critical area where the brightness drops to 50%.

For the selected eye box standard, the width and height parameters are shown in the table below:

axis	Eye box size (mm)
x-axis (y=0 mm)	16.3
y-axis (x=0 mm)	16.3

a meter (measuring sth) 20 Table 20: Measurement results of the eye box

8.10.Pixel Density Measurement

Light Measuring Devices (LMD):

Instrument Systems LumiTop 5300 ARVR (2D Light Measurement Equipment)

- Entrance pupil: 3mm
- Focal length: 1000mm

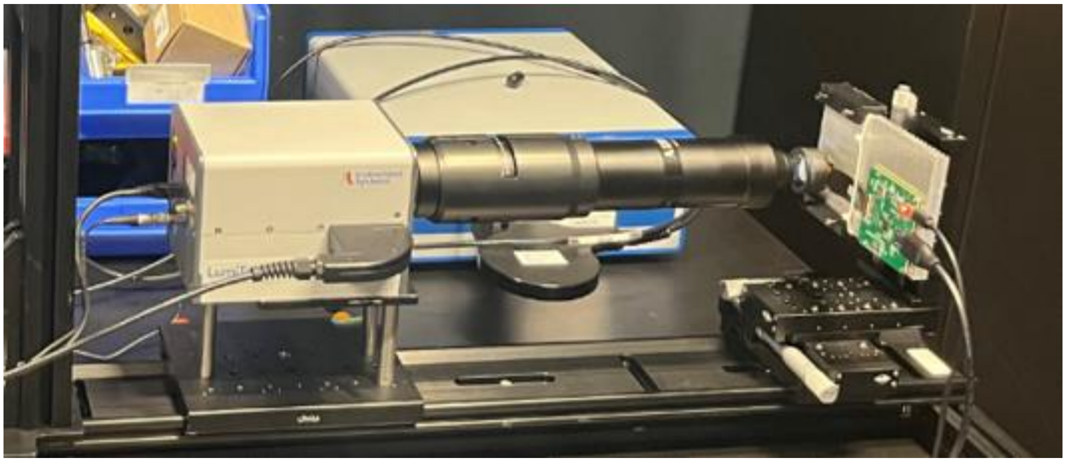


Figure 45 Measuring platform for pixel density measurement

Device Under Test (DUT):

NED device with Pancake optics and TFT-LCD display with 1600 px x 1600 px resolution.

Test Patterns:

Use the speckle pattern used for aberration measurements:

- Consists of 15x15 spots.
- The overall size of the test pattern is 1600 pixels x 1600 pixels.
- The interval between spots is set to 100 pixels.
- Each spot has a radius of 15 pixels.

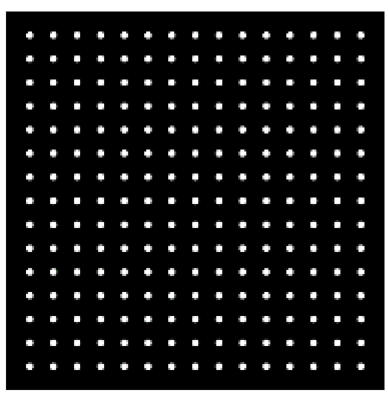


Figure 46 : Speckle pattern for pixel density measurements

Measurement:

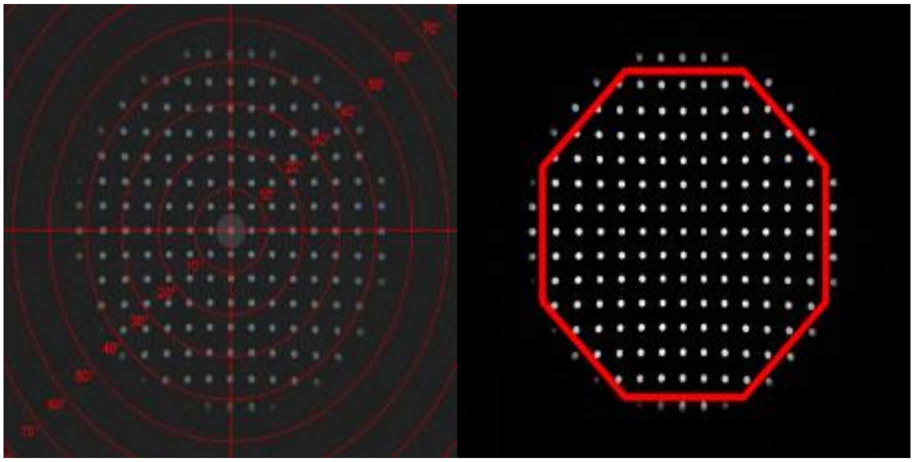


Figure 47 : Selected spots for data analysis (left) and the range of fields of view superimposed on the same image (right)

Analysis:

- First calculate the area of each spot.
- In the image, each pixel corresponds to an angle of 0.02396°, which is the conversion factor c obtained by polar calibration.
- PAD (pixels per degree) is calculated as follows:
    1. The area of the spot on the display device (test pattern) is a=709 pixels^2.
    2. Spot area measured using a photometric device.
    3. The formula for calculating the PAD of a speckle is $D_{blob} = \sqrt{\frac{a}{A*c^2}}$, where the units are pixels per degree (px/deg, i.e., ppd).
- The figure below shows the PAD values for different spots.
    1. The center position had the best PAD value of 17.1 PPD.
    2. In the edge region of the image, the PAD value drops to about 15 PPD.

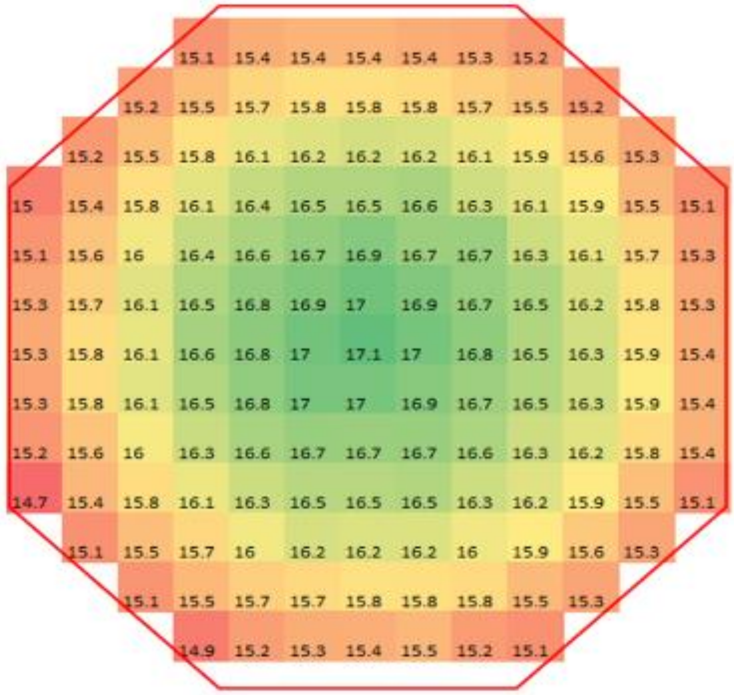


Figure 48 : Pixel Density Results

9. Conclusion

This brochure focuses on the key points related to the measurement of Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR) devices and components using optical measurement equipment, covering an overview of the application, standards and definitions, optical measurement equipment, measurement methods, measurement platforms, and measurement examples.

At the application level, VR/MR headsets, which typically completely close off the user's field of view, are designed to impact measurements with components that include displays and lenses, while AR headsets allow users to view the real world while overlaying virtual content with components that include small displays and thin optics. For VR devices, the important measurements are brightness, color, distortion, contrast and sharpness.

In terms of standards and definitions, the manual details common dimensional specifications and terminology for AR/VR/MR head-mounted displays and explains the various associated coordinate systems; the DUT (Device Under Test) and the LMD (Light Measuring Device) each have their own coordinate systems, which are related to the position and angle of view of a human's eye, in order to ensure accurate measurements and displays. Common terminology in

AR/VR head-mounted display devices is also introduced, as well as the use of Cartesian and spherical coordinate systems in measurement.

The performance evaluation of AR/VR/MR devices needs to follow a series of international standards covering optical measurement, image quality, ergonomics and many other aspects. For example, the IEC 63145 series of standards provide unified terminology, test methods and performance indicators for eyewear display devices to ensure the comparability and consistency of different devices; the ISO 9241-333:2017 standard focuses on the ergonomic requirements of stereoscopic display devices to ensure user comfort and visual health; the ANSI/INFOCOMM 3M-201 standard provides measurement and specification methods for contrast ratios for projected image systems. Adherence to these standards enables manufacturers to develop AR/VR devices with superior performance and user experience, contributing to the robust growth of the industry.

As a key tool for evaluating the optical performance of a device, a Light Measuring Device (LMD) needs to meet stringent specifications, such as interpupillary diameter, angular accuracy, and translation stage accuracy. The imaging light measurement device (ILMD) should be able to provide 2D images of the DUT and support the conversion between Cartesian and spherical coordinate systems, and the LMD should also meet different functional requirements, such as spectral range, bandwidth, wavelength accuracy, etc. In addition, depending on the measurement requirements, the LMD can use the pupil diameter, angular accuracy, and translation stage accuracy. In addition, depending on the measurement requirements, the LMD can use pupil points or eye movement points to simulate various observation scenarios.

The Measurement Methods chapter provides an in-depth explanation of a variety of test methods, covering aspects such as eye alignment, optical characterization, and image quality. Each test method specifies the type of optical measurement device (2D LMD or point LMD) to be used and whether mobile devices are required. Eye alignment can be done in various ways, such as by specific attributes or dimensions based on ICDM standards, or by using crosshairs, center brightness, center resolution, field of view, lateral chromatic aberration, comet aberration, etc., and each method has different measurement parameters and judging criteria. Optical characteristics measurement includes brightness, brightness and contrast uniformity, chromaticity and color gamut, chromaticity uniformity, contrast, etc. Different methods correspond to different types of LMDs and have corresponding measurement parameters and reference standards. Image quality measurement involves field of view, eye box, aberration, color alignment error, Michelson contrast, focal length and virtual image distance, MTF, black/white contrast, gamma, pixel angular density, etc., and each measurement method has specific applicable equipment, measurement parameters, and relevant standards. In addition, the document provides an overview of the test method, the required test pattern, and the definition of the measurement points, which can be determined according to the display size or field of view, to ensure accurate and reliable measurement results.

In terms of testbed setup, the key to aligning AR/VR optical measurement devices is to ensure that the coordinate system of the measurement device (LMD) and the coordinate system of the device under test (DUT) are perfectly aligned. The alignment process consists of crosshair alignment and speckle alignment, where crosshair alignment is used to adjust the position and angle of the DUT, and speckle alignment is used to check the consistency between the DUT and the optical axis. During the alignment process, azimuth, elevation, rotation, eye distance, and X/Y axis positions are precisely controlled to ensure the accuracy and repeatability of the measurement results.

Measurement examples cover measurements of uniformity and contrast, distortion, sharpness, DUT characteristics, and more, and comprehensively demonstrate the specific measurement process, equipment used, DUTs, test patterns, measurement steps, and data analysis.

List of Figures

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