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Ergonomics of human-system interaction —

Part 380:
Survey result of HMD (Head-Mounted Displays) characteristics related to human-system interaction

Reference number
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

A list of all parts in the ISO 9241 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The evolution of electronic devices has led to the growing popularity of head-mounted displays (HMDs) for direct human–machine interaction. Although ISO 9241-303 and ISO 305 addressed HMDs as 'virtual displays', the information in these documents was limited to devices available at the time, and the evolution of HMDs requires new parameters to cover the interactions between the user and the HMD itself. To provide the latest information to suppliers, users, and anyone who interacts with HMDs, it is important to establish which HMD characteristics need to be considered.

Unlike a conventional display, a viewer wears an HMD to see the displayed images. In most cases, when images are shown on a conventional display, there is a certain distance between the viewer and display. However, as stated, a viewer of an HMD wears it, usually on their head. Obviously, such viewing conditions affect the viewer in certain ways, by not only the optical characteristics (which are the main concerns for conventional displays) but also other physical characteristics such as weight. Therefore, discussing the ergonomic considerations of HMDs requires a systematic approach by considering several aspects simultaneously, which is the aim of this document.

NOTE The International Electrotechnical Commission (IEC) also works on the standardization of HMDs (the IEC calls them 'eyewear displays'). At the time of publication, the following IEC standards are available and are being developed:

IEC TR 63145-1-1: 2018: *Eyewear display - Part 1-1: Generic introduction*

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 63145-22-10:2020: *Eyewear display - Part 22-10: Specific measurement methods for AR type - Optical properties*

Ergonomics of human-system interaction —

Part 380:
Survey result of HMD (Head-Mounted Displays) characteristics related to human-system interaction

1 Scope

This document provides information based on a study of the characteristics of head-mounted displays (HMDs) regarding the ergonomics of human–system interaction. Although this document covers the broad range of ergonomics issues that arise, it specifically provides more-detailed information about the visual aspects of the interaction, and it provides information that could form the basis for future possible standards related to HMDs.

NOTE It is preferable to take systematic approach to consider characteristics of HMD, since HMD affects a viewer not only by visual aspects, but also by some other physical aspects.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
head-mounted display
HMD
electronic device that shows information on one or more displays attached to the head of a human

3.2
virtual reality
VR
artificial environment presented by a computer

Note 1 to entry: See Figure 1.

Note 2 to entry: Including telepresence and interaction with and reaction from the virtual environment.

[SOURCE: ISO/IEC TR 18121:2015, 3.6]

3.3
mixed reality
MR
physical and digital (virtual) objects co-exist and interact in real time

Note 1 to entry: See Figure 1.

3.4
augmented reality
AR
reality that has virtually added information

Note 1 to entry: See Figure 1.

Note 2 to entry: AR is used in ISO 9241-910 with no definition.

Note 3 to entry: AR is used in ISO/IEC TR 18120:2016 with no definition.

Note 4 to entry: AR is used in ISO 19154:2017 with no definition.

Note 5 to entry: AR is used in ISO/IEC TR 19566-1:2017 with no definition.

3.5
reality
world or the state of things as they exist

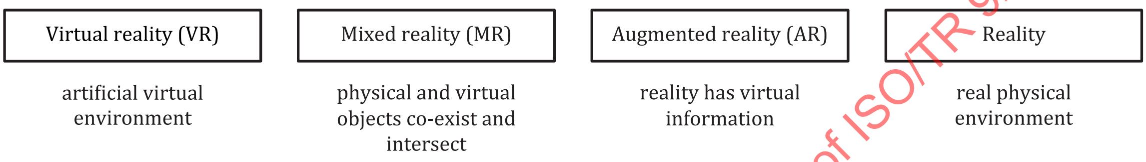


Figure 1 — VR, MR, AR, Reality

Note 1 to entry: See Figure 1.

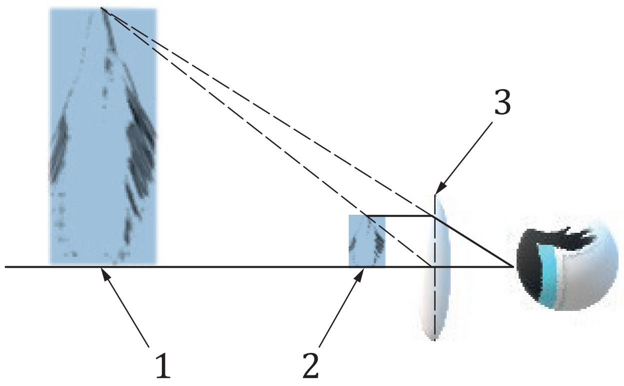
3.6
exit pupil
vertical/horizontal dimension of the QVS (qualified viewing space)

[SOURCE: ISO 9241-302]

4 Head-mounted displays (HMDs)

An HMD is an electronic display device that provides visual information by using one or more displays that are placed on a human head and secured by elastic straps or earpieces or integrated in a helmet (see Figure 2). An HMD shows information by using virtual images rather than real ones (see Figure 3). Most HMDs consist of one or more electronic displays and proper optics that treat the images on the display or displays so that they can be seen by one or more human eyes. In some cases, there is no physical display, only optics (see Figure 4). Because of these considerable differences from conventional displays, numerous characteristics need to be considered regarding human–system interaction. This document explores those characteristics and point out new ways of evaluating HMDs regarding their users (viewers).

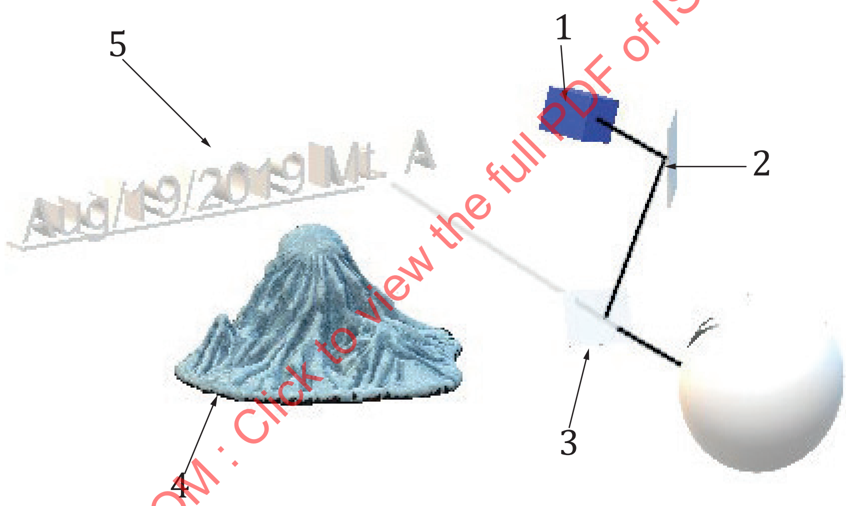
Figure 2 — Example of a head-mounted display



Key

1 virtual image
2 real image on a display
3 convex lens

Figure 3 — Example of a virtual image



Key

1 laser source
2 mirror array
3 half mirror
4 real object
5 virtual image (projected image)

Figure 4 — Example of a direct scanning HMD

5 Categories of HMDs

5.1 General

There are several ways to categorize HMDs, such as by the type of images that the device shows, how the device forms a virtual image, ocularity, and physical configuration (Figure 5)

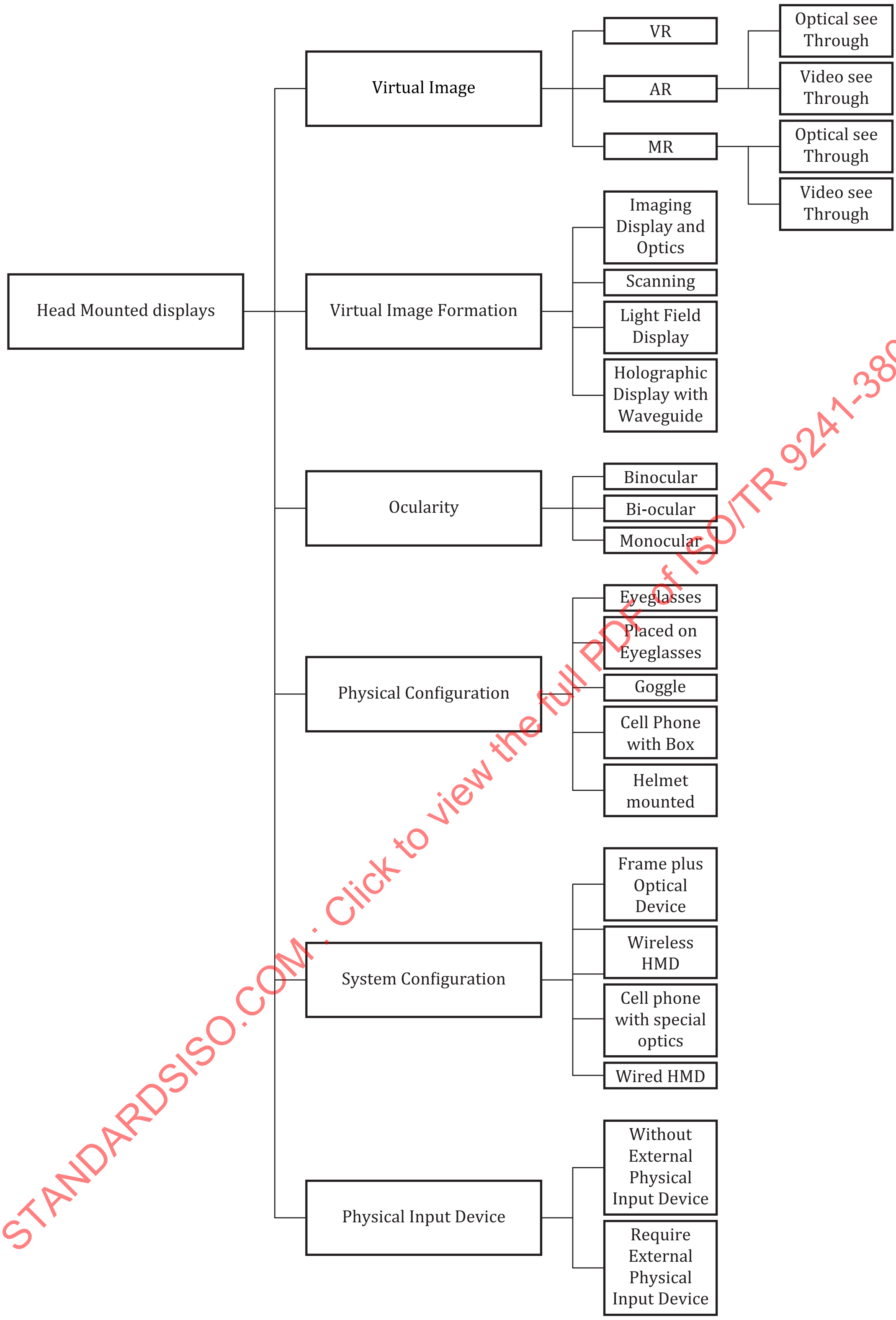


Figure 5 — Example of categorizing HMDs

5.2 Categorized by virtual image

5.2.1 VR type

The VR type of HMD displays only computer-generated images (virtual images). The HMD covers the viewer's eyes completely, meaning that they can see nothing except the displayed images (see Figure 6).

Figure 6 — Example of a VR HMD

5.2.2 AR type

The AR type of HMD presents images of the real surrounding environment by using either transparent optics (see-through AR type) or electro-optical devices, such as a video camera (video-see-through type), and it shows computer-generated images (virtual images) by using certain electro-optical devices (see Figure 7).

Figure 7 — Example of an AR type HMD

5.2.3 MR type

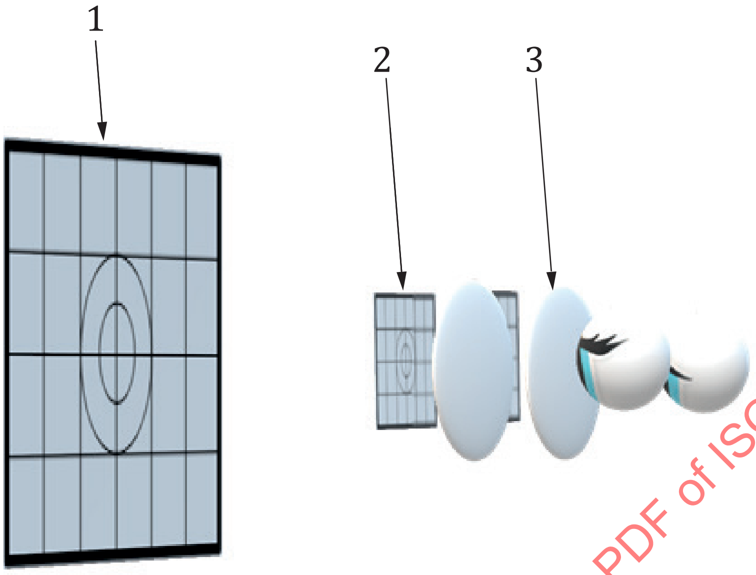
The MR type of HMD presents mainly computer-generated images and imposes real images (outside scenery) by means of either video see-through or see-through optics (see Figure 8).

Figure 8 — Example of an MR type

5.3 Categorized by virtual image formation

5.3.1 Imaging display and optics

This type of HMD shows virtual images by both showing them on displays and forming them by using optics (see Figure 9).



Key

1 virtual image

2 displays with real image

3 convex lenses

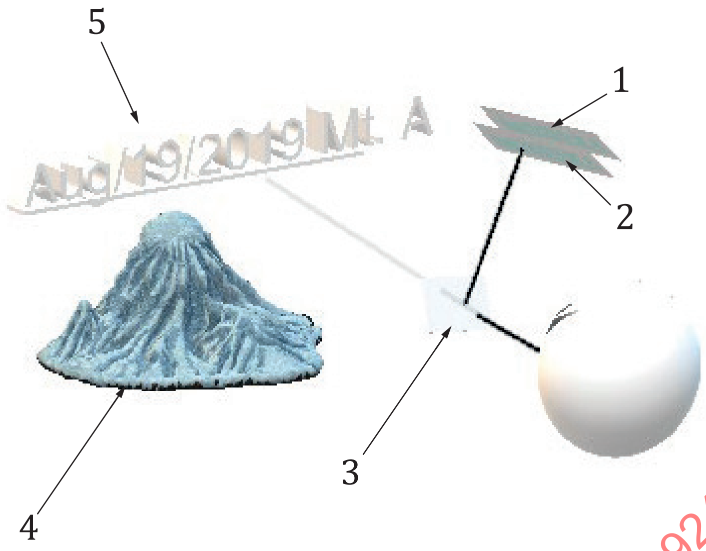
Figure 9 — Example of an image forming type

5.3.2 Scanning type

This type of HMD does not form images by any means; rather, it uses light rays to scan the human retina via certain optics (see Figure 4).

5.3.3 Light field type

The light-field approach involves providing a near-eye display by using certain optics, such as those based on micro-lenses (see Figure 10).



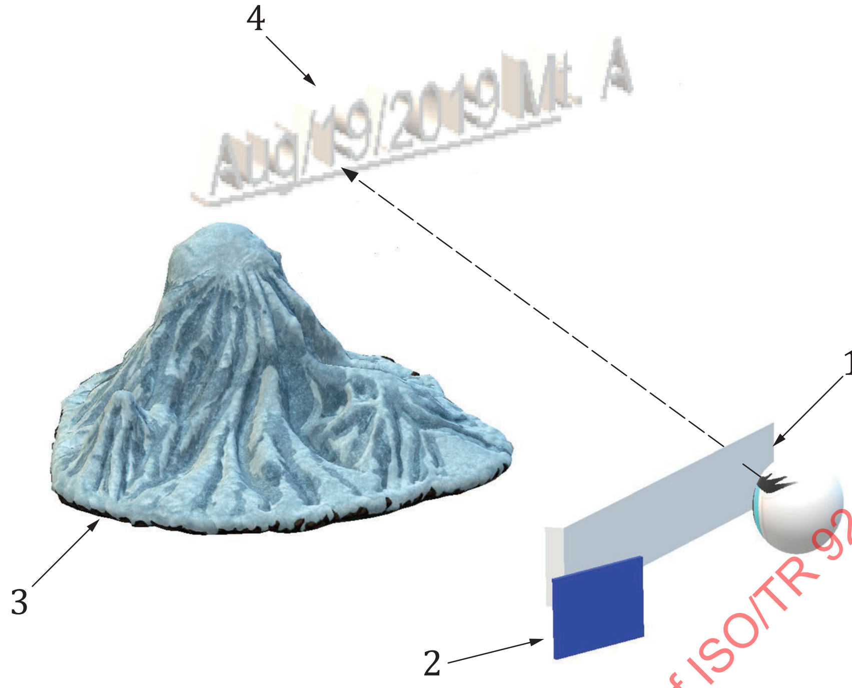
Key

1 LCD
2 micro lens array
3 half mirror
4 real object
5 virtual image (projected image)

Figure 10 — Example of a light field display

5.3.4 Holographic display with waveguide type

holographic with waveguide to provide near-eye display by using certain optics, such as micro lens-based optics (See Figure 11).



Key

1 light guiding element
2 LCD
3 real object
4 virtual image (projected image)

Figure 11 — Example of a holographic with waveguide display

5.4 Categorized by ocularity

5.4.1 Binocular

The binocular type of HMD shows independent images on each imaging device by using stereo separation and stereo convergence (see Figure 12).

NOTE Two separate images are seen using two separate displays and lenses.

Figure 12 — Example of a binocular display

5.4.2 Biocular

The bi-ocular type of HMD shows the same images on each imaging device (see Figure 13).

NOTE One image is seen using one display through two separate mirrors and lenses.

Figure 13 — Example of a biocular display

5.4.3 Monocular

The monocular type of HMD shows images on one imaging device (see Figure 14).

NOTE seeing one image by using one display and one lens

Figure 14 — Example of a monocular display

5.5 Categorized by physical configuration

5.5.1 Eyeglasses type

This type of HMD is somewhat like typical eyeglasses, having optics, a frame, a bridge over the nose and arms that rest on the ears (see Figure 15).

NOTE Eyeglasses that have a display

Figure 15 — Example of eyeglasses type of HMD

5.5.2 Placed on eyeglasses

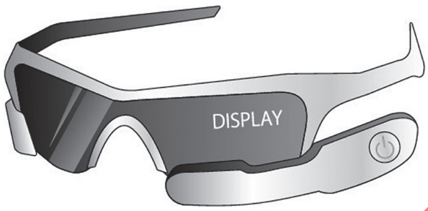
This type of HMD is designed to be put onto eyeglasses (see Figure 16).

NOTE Display with optics on eyeglasses.

Figure 16 — Example of type of HMD that is placed on eyeglasses

5.5.3 Frame plus optical device

This type of HMD has a frame for mounting on the viewer's head and one or more optical devices attached to that frame (see Figure 17).



NOTE Display and optics on an eyewear frame.

Figure 17 — Frame and optical devices type

5.5.4 Goggles

HMD looks like goggles (see Figure 18).

Figure 18 — Example of a goggle-type HMD

5.5.5 Smart phone with box

This type of HMD consists of a smartphone and a box (see Figure 19).

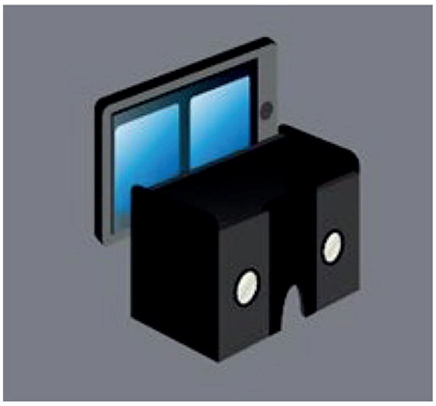


Figure 19 — Smart phone with box type

5.5.6 Helmet mounted

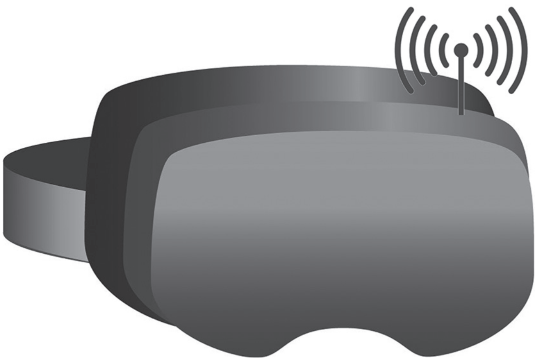
This type of HMD is attached to a helmet and is usually called a 'helmet-mounted display' (see Figure 20).

Figure 20 — Example of a helmet-mounted HMD

5.6 Categorized by system configuration

5.6.1 Wireless HMD (standalone)

HMD works without having any other connected devices such as PC (see Figure 21).



NOTE HMD has only a wireless connection.

Figure 21 — example of a wireless HMD

5.6.2 Smart phone with special optics

This type of HMD consists of a smartphone and certain special optics (see Figure 19).

5.6.3 Wired HMD

This type of HMD is connected by a wire to another device such as a PC (see Figure 22).

NOTE HMD with a wired connection.

Figure 22 — Example of a wired HMD

5.7 Categorized by physical input devices for HMD system

5.7.1 HMD System without external physical input devices

This type of HMD system has no external physical input devices, such as remote control (see Figure 23).

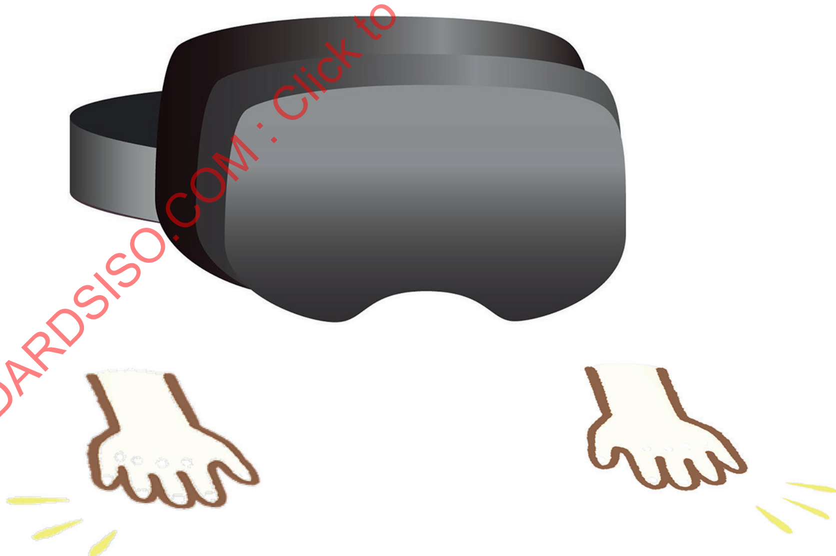
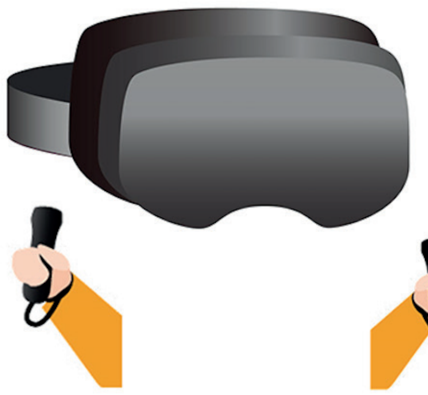


Figure 23 — Example of an HMD without external physical input devices

5.7.2 HMD System with external physical input devices

This type of HMD system has external physical input devices, such as one or more wands, a steering wheel and/or gesture-based interaction devices, such as data gloves with motion tracking (see Figure 24).



a) HMD system with wireless wands

b) HMD system with steering wheel

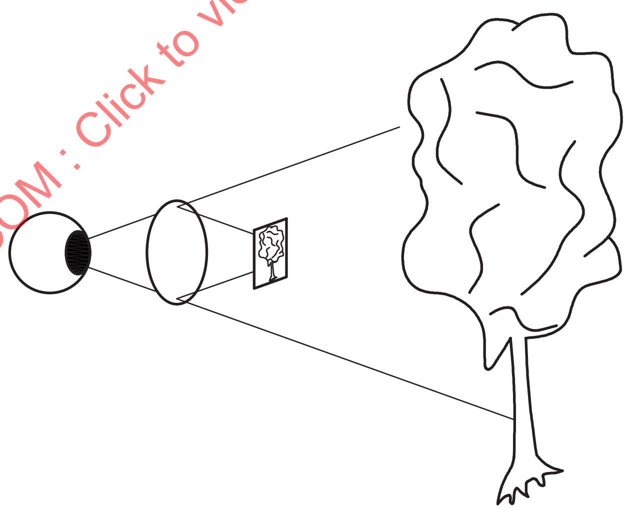
Figure 24 — Examples of an HMD with external physical input devices

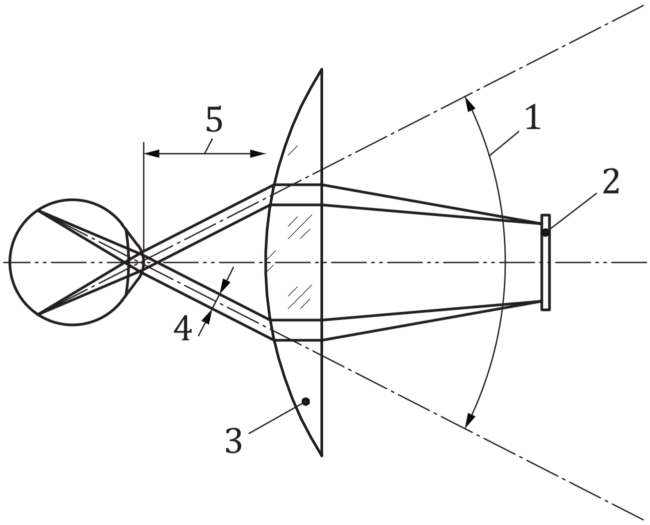
6 HMD human-system interaction characteristics

6.1 Optical characteristics

6.1.1 General

Figure 25 shows the principles of an HMD.





Key

1 field of view
2 display
3 optical components
4 exit pupil
5 eye relief (see 6.1.1.5)

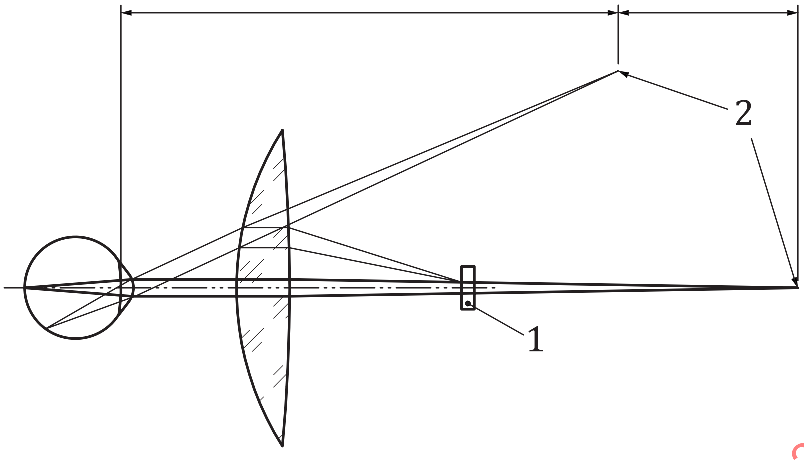
Figure 25 — HMD using a lens to create a virtual image from a micro-display (ISO 9241-302, Figure 11 therein)

6.1.1.1 Focus

This is defined as the point where the geometrical lines or their prolongations conforming to the rays diverging from or converging toward another point intersect and give rise to an image after reflection by a mirror or refraction by a lens or optical system (see Figure 27); modified from ISO 9241-302:2008, 3.5.24, which is based on the Merriam-Webster dictionary.

Note The definition of focal distance in ISO 9241-302:2008, 3.5.24 was incorrect.

The figure for focal distance in ISO-9241-302 (see Figure 26) was not expressed properly and will be replaced by Figure 27 in this document.



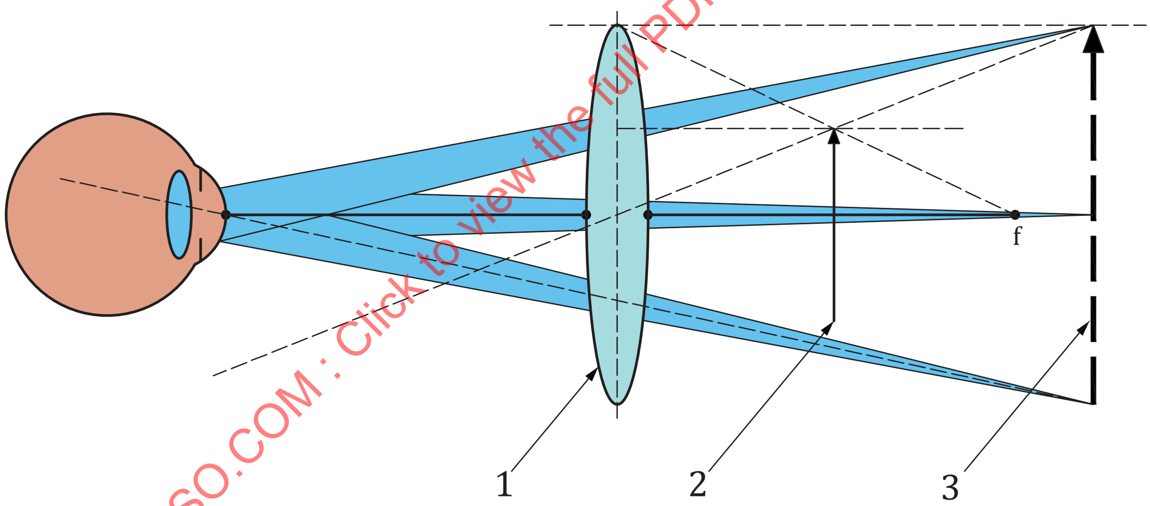
Key

1 display

2 apparent focal points

Figure 26 — Focus distance (ISO 9241-302) ; not expressed correctly

Note Focus distance is not correctly expressed by Figure 26.



Key

1 positive lens magnifier

2 object

3 virtual image

Figure 27 — Focus

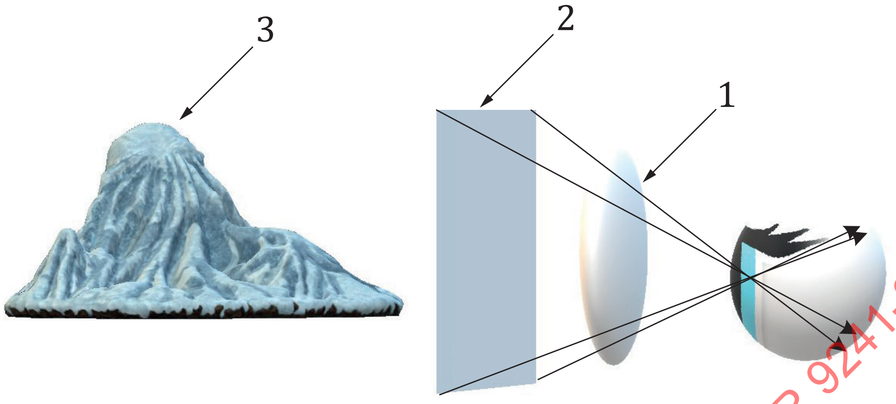
6.1.1.2 Field of view (FOV)

For a conventional display, the FOV—that is. the width to which an image from a display spread—is defined by the visual angle subtended by the image at the eye pupil (see Figure 28). However, for an HMD, its viewer sees an image as a virtual one, so this definition is not directly applicable. For a detailed discussion, see Section 5.2 of IEC 63145-1-1. As stated in IEC 63145-1-1, the FOV is related to the following characteristics:

— luminance, chromaticity and contrast (including uniformity);

— distortion, resolution (Michelson contrast), colour registration error (chromatic aberration) and virtual image distance.

Note For a conventional display, the FOV is defined as the angular region subtending the active area of the display as observed from the designed viewing direction or other eye position (ISO 9241-302).



Key

1 convex lens

2 displays with real image

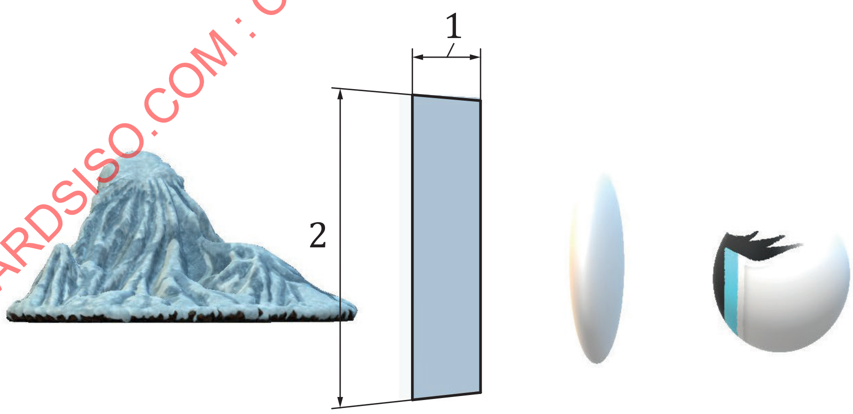
3 virtual image

Figure 28 — Field of view (FOV)

To obtain FOV determined, those characteristics need to be measured. Measurement method of FOV is defined in the section 6.7 Field of view FOV of IEC 63145-20-10.

6.1.1.3 Aspect ratio

The aspect ratio of an image is the ratio of its height to its width (see Figure 29).



Key

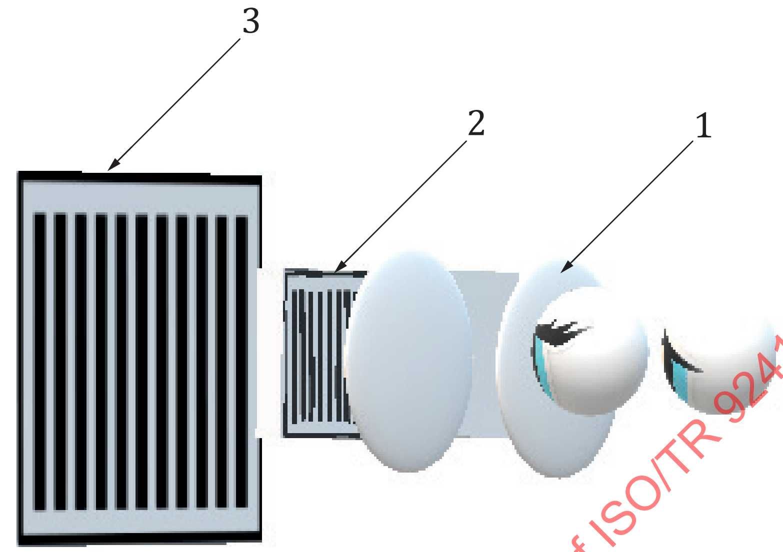
1 width

2 height

Figure 29 — Aspect ratio

6.1.1.4 Spatial frequency

The spatial frequency is defined as the image-plane irradiance distribution at the measuring point (see Figure 30).



Key

1 convex lens

2 displays shows black and white grill or grating image

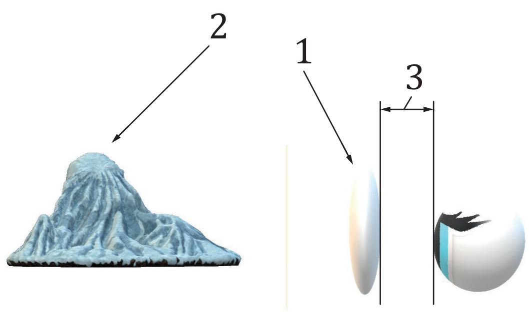
3 virtual image

Figure 30 — Spatial frequency

The method for measuring spatial frequency is defined in Section 6.5 of IEC 63145-20-20.

6.1.1.5 Eye relief

Eye relief is the distance from the last edge of the optics to the front of the human eye. When an HMD is to be worn over eyeglasses, it needs to be designed to have enough space to accommodate the glasses. Also, eye relief (e.g., the positioning of the HMD along the y-axis) is important for comfort, especially for the ciliary muscles.



Key

1 convex lens

2 virtual image

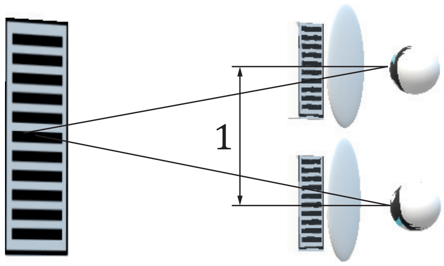
3 eye relief

Figure 31 — Eye relief

6.1.2 Distance between eyes

6.1.2.1 Interocular distance adjustment

The interocular distance, pupillary distance, or interpupillary distance (IPD) is the distance between the centres of the pupils of the eyes. Interocular distance adjustment is a function of an HMD to adjust the distance between the images to fit the viewer's interocular distance (see Figure 32).



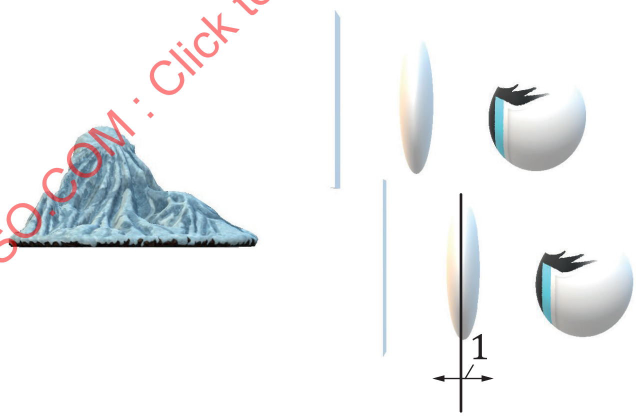
Key

1 interocular distance

Figure 32 — Interocular distance

6.1.2.2 Dioptre adjustment

Dioptre adjustment involves compensating for the viewer's refractive error, without which some viewers would have difficulties in seeing proper images. If an HMD has small eye relief and no dioptre adjustment, then a viewer with a certain refractive error cannot use this HMD properly. However, dioptre adjustment cannot be applicable for astigmatism. Especially for VR applications, the viewer needs normal stereoscopic depth perception. Stereo and visual acuity tests can be done in order to perceive the virtual information as intended (see Figure 33).



Key

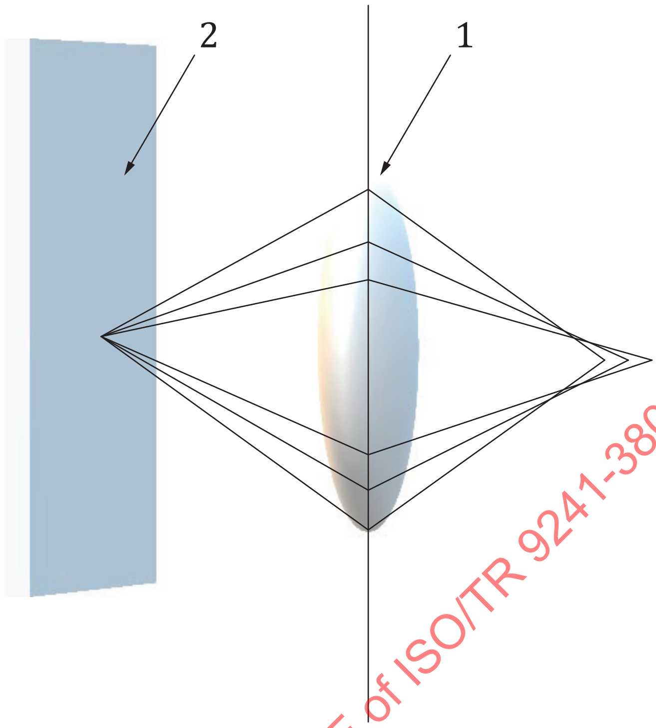
1 dioptre adjustment

Figure 33 — Dioptre adjustment

6.1.3 Distortion and aberration

6.1.3.1 Spherical aberration

With spherical aberration, an image appears blurred or softened (see Figure 34).



Key

1 convex lens

2 display with real image

Figure 34 — Spherical aberration

6.1.3.2 Astigmatism

With astigmatism, horizontal or vertical lines would appear out of focus (Figure 35).

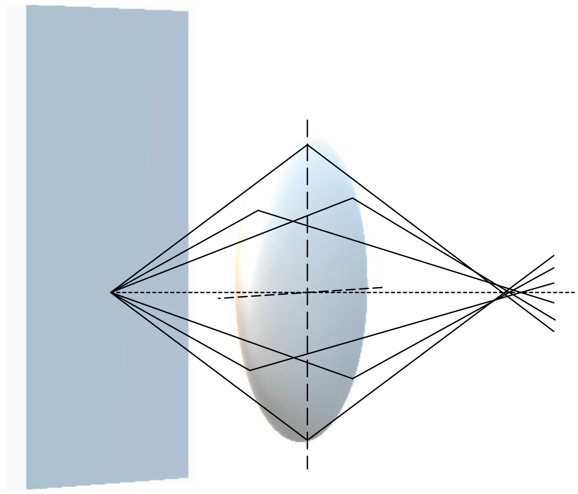


Figure 35 — Astigmatism

6.1.3.3 Field curvature

With field curvature, a flat object does not appear flat, and this is caused by the centre of the image being in focus whereas the periphery is not (see Figure 36).

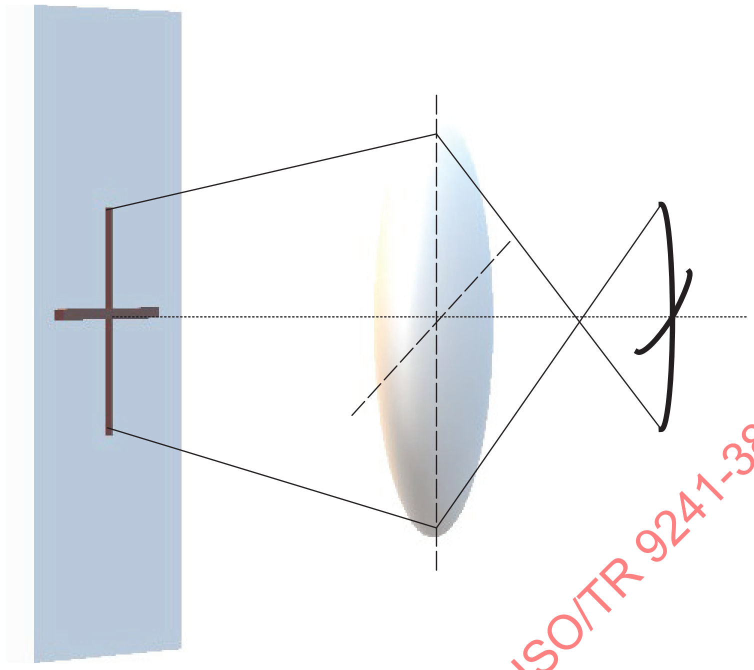


Figure 36 — Curvature of field

6.1.3.4 Chromatic aberration

Because of the different wavelengths of light, a lens would have to have different refractive indices to be able to focus all colours at the same point. An image with chromatic aberration appears blurred and suffers colour 'flaring' around the fringes of objects (see Figure 37).

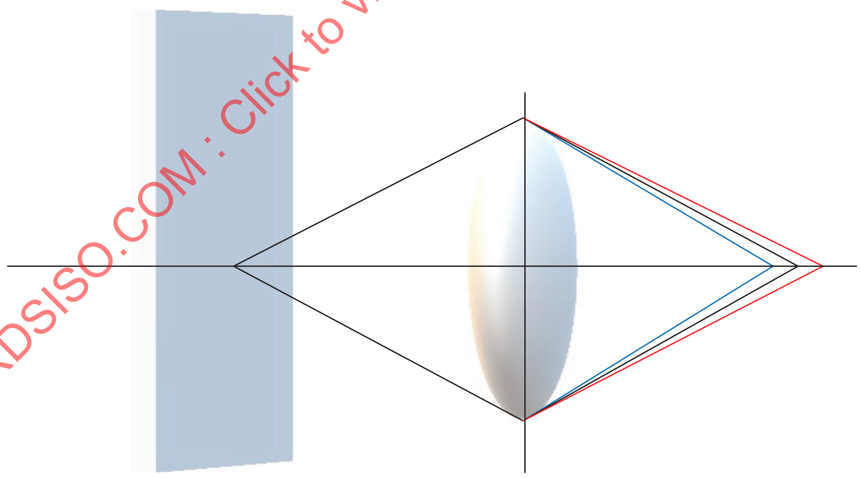
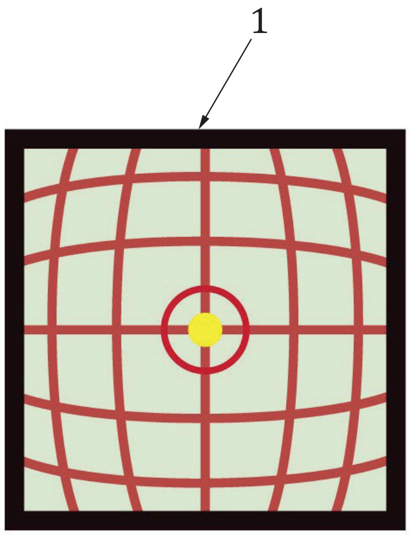


Figure 37 — Chromatic aberration

6.1.3.5 Distortion

The image as viewed is geometrically different from as intended, such as pincushion or barrel distortion (see Figure 38).



Key

1 image seen via HMD has distortion

Figure 38 — Distortion

6.1.4 Inter-Ocular optical properties

The following are optical properties related to binocular vision (see Figure 39).

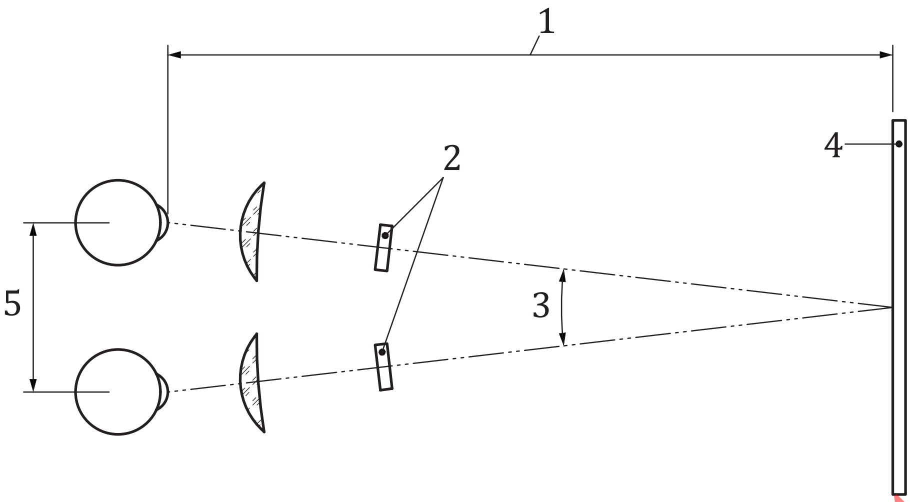
Figure 39 — Binocular vision

As shown in Figure 39, binocular vision typically involves two separate sets of optics to separate images onto two separate displays, and consequently it has several unique properties.

Note When measuring HMD optics, it is important to show the same image on both displays.

6.1.4.1 Binocular convergence

Binocular convergence is the rotation of the eyes in their sockets to focus on a single virtual object, and the method for measuring it is as shown in Figure 40.



Key

1 convergence distance

2 displays with real image

3 convergence angle

4 fused virtual screen

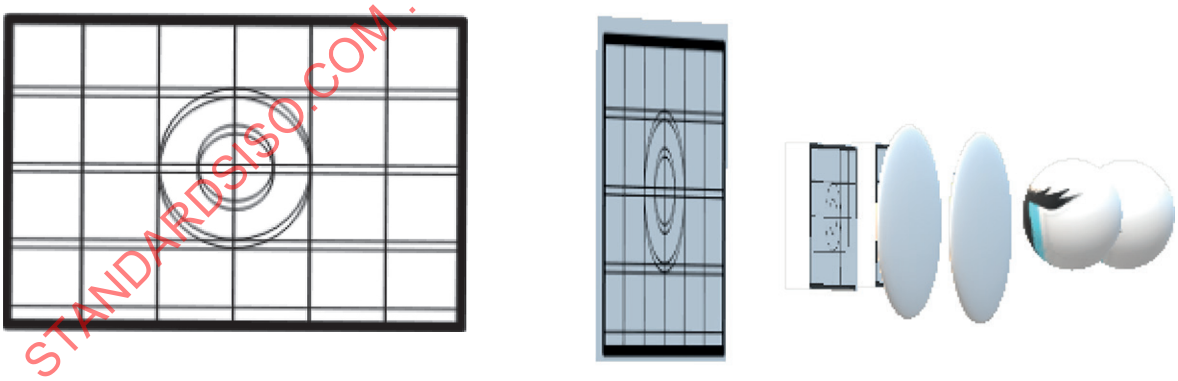
5 interpupillary distance

Figure 40 — Convergence point (ISO 9241-302, Figure 12 therein)

Note When measuring HMD optics, because an HMD sometimes does one or more functions to control the images on both displays, it is important to ensure that the HMD shows the same image on both displays.

6.1.4.2 Vertical misalignment

In vertical misalignment, because of optical misalignment of the imaging system of an HMD, a virtual image does not appear as one image (see Figure 41).



a) Misaligned image seen by HMD

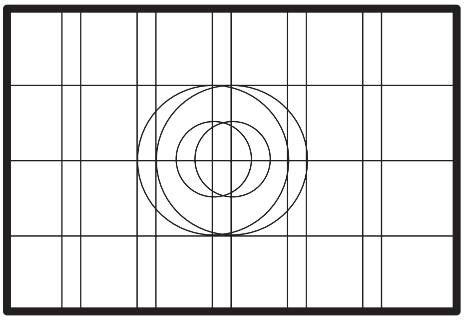
b) Imaging system

Figure 41 — Vertical misalignment

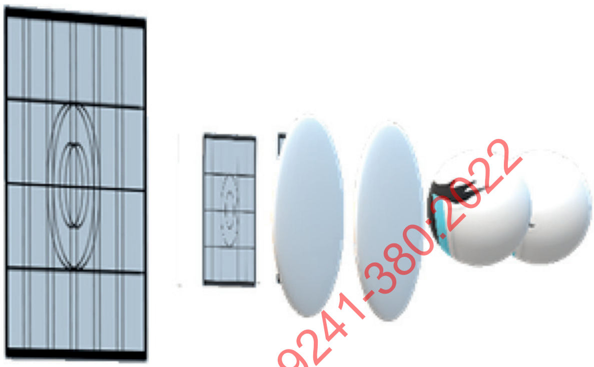
6.1.4.3 Horizontal misalignment (unintended)

Horizontal misalignment involves the unintended optical misalignment of an HMD imaging system, whereby a horizontal offset between the images is introduced that would result in the appearance of double images, depth distortion, increased fusional effort and other issues with binocular fusion and stereopsis (see Figure 42).

Note Horizontal misalignment is distinct from the intentional depth-dependent binocular disparity that is typically present in stereoscopic displays (see ISO 9241-392, Annex C).



a) Misaligned image seen by HMD

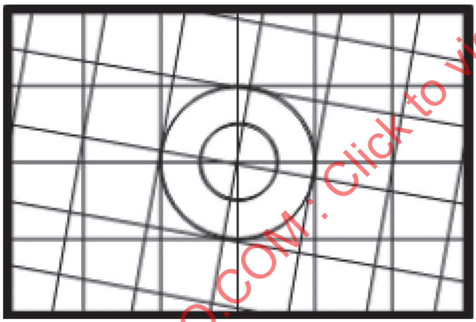


b) Imaging system

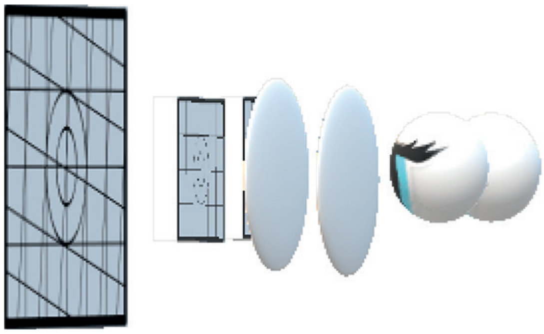
Figure 42 — Horizontal misalignment

6.1.4.4 Rotation misalignment

In rotational misalignment, because of optical misalignment of the imaging system of an HMD, a virtual image does not appear as one image (see Figure 43).



a) Misaligned image seen by HMD

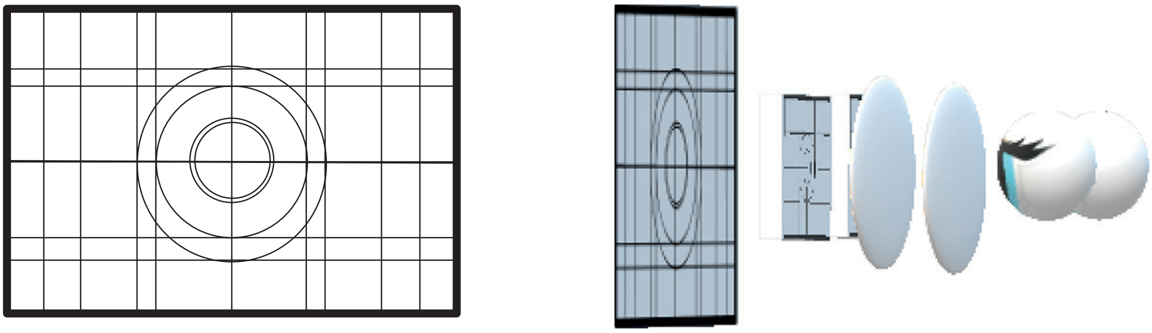


b) Imaging system

Figure 43 — Rotation misalignment

6.1.4.5 Enlargement misalignment

In enlargement misalignment, because of optical misalignment of the imaging system of an HMD, a virtual image does not appear as one image (see Figure 44).

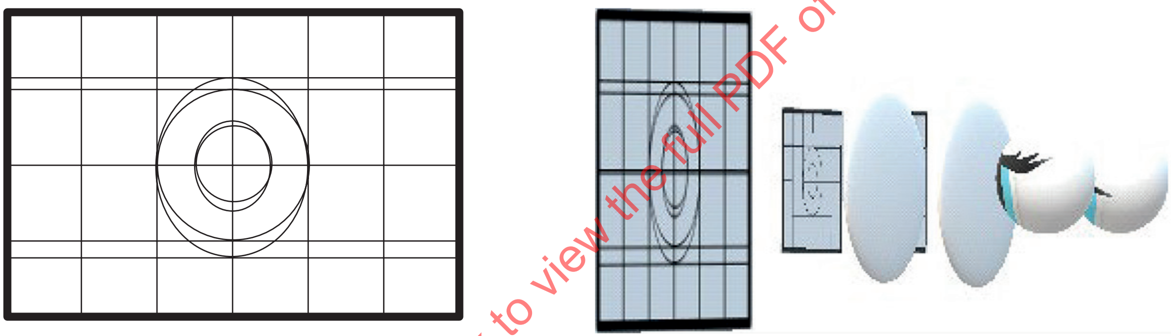


a) Misaligned image seen by HMD b) Imaging system

Figure 44 — Enlargement misalignment

6.1.4.6 Vertical enlargement misalignment in both images

Vertical enlargement misalignment is defined as the vertical enlargement misalignment between both images (see Figure 45).

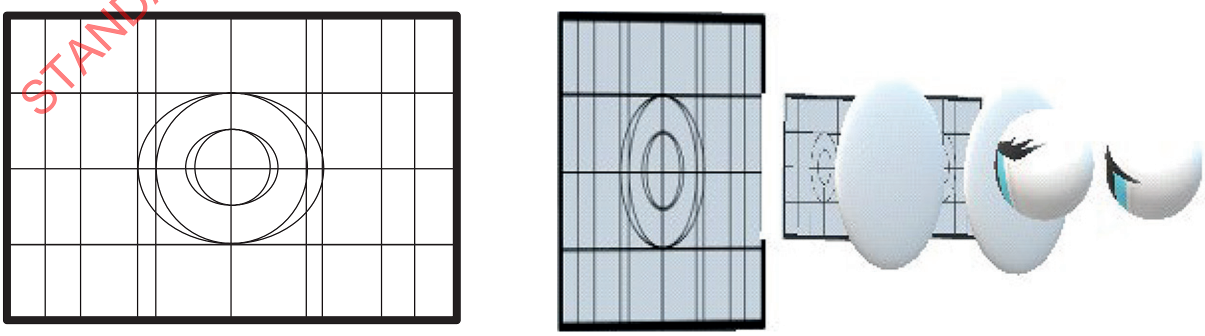


a) Misaligned image seen by HMD b) Imaging system

Figure 45 — Vertical enlargement misalignment in both images

6.1.4.7 Horizontal enlargement misalignment in both images

Horizontal enlargement misalignment is defined as the horizontal enlargement misalignment between both images (see Figure 46).

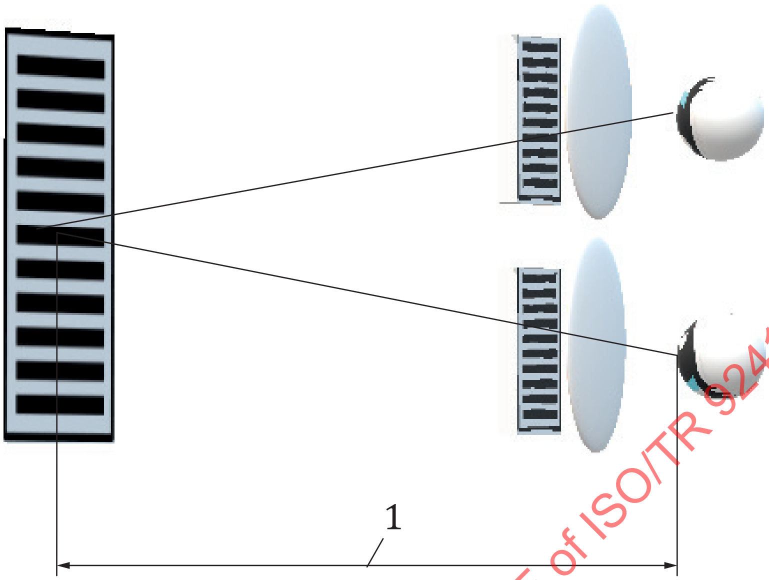


a) Misaligned image seen by HMD b) Imaging system

Figure 46 — Horizontal enlargement misalignment in both images

6.1.4.8 Eye–virtual image distance

The eye–virtual image distance is defined as the distance between the front of the eye and the position of the virtual image (see Figure 47).



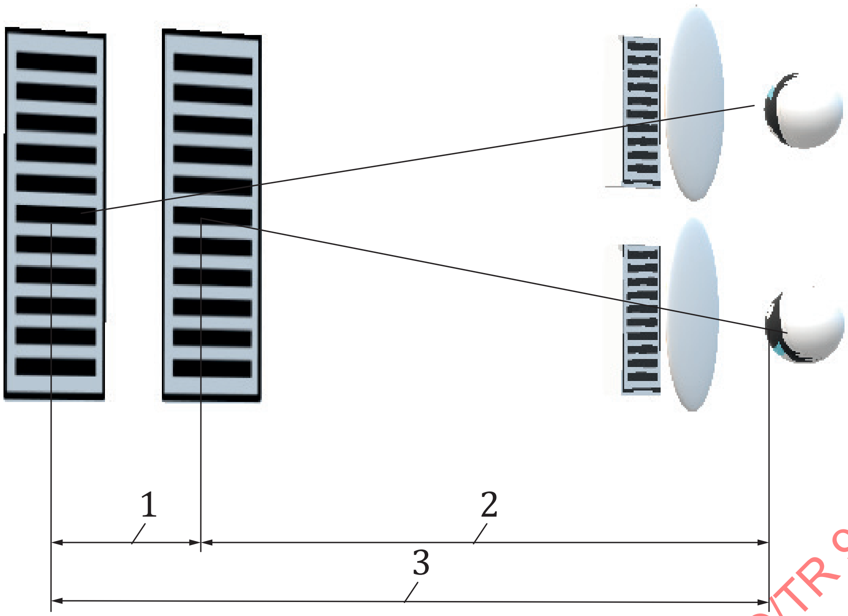
Key

1 focusing distance

Figure 47 — Focusing distance, virtual image

6.1.4.9 Eye–virtual image distance difference in both images

The eye—virtual image distance difference is defined as the focusing misalignment between both images (see Figure 48).



Key

1 eye–virtual image distance difference

2 eye-virtual image distance for left eye

3 eye-virtual image distance for right eye

Figure 48 — Focusing difference in both images

6.1.4.10 3D image capability

For an HMD to have 3D image capability, it has two displays and two sets of optics; 3D image capability is only achievable with binocular optics and when the viewer has normal stereoscopic depth perception.

6.1.5 For AR/MR

6.1.5.1 Transmittance property (see through type)

Transmittance is the physical property of a material whereby it allows light to pass through it without being scattered (see Figure 49 and Figure 50). There are two types of transmittances: hemispherical (diffuse) transmittance T, which is all transmittance, and regular transmittance T_{Ω}, which is a part of diffuse transmittance and is used to describe how good that transparency is. As an example, the total transmittance T of a material is defined as;

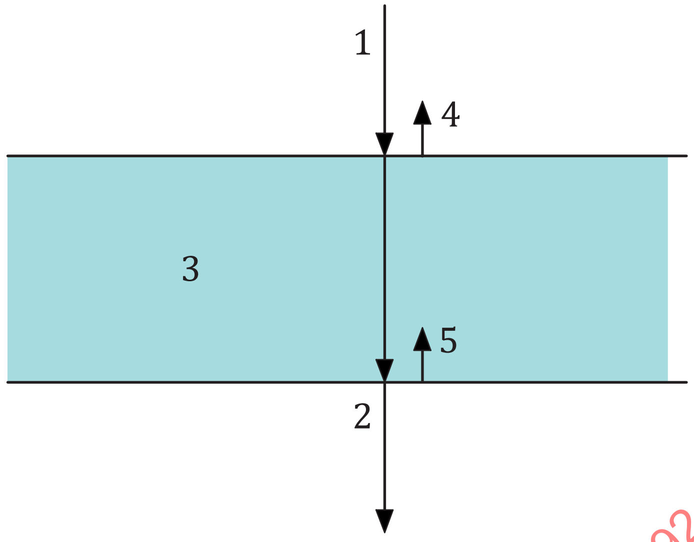
$$T = \frac{\Phi_e^t}{\Phi_e^i} \tag{1}$$

where

T is transmittance, and

Φ_e^t is the radiant flux transmitted by the upper surface in Figure 49, and

Φ_e^i is the radiant flux received by the lower surface.



Key

1 Φ_e^t - is radiant flux received by upper surface

2 Φ_e^i is radiant flux transmitted by lower surface

3 α : absorption of material

4 R_1 : reflectance

5 R_2 : reflectance

Figure 49 — Transmittance properties

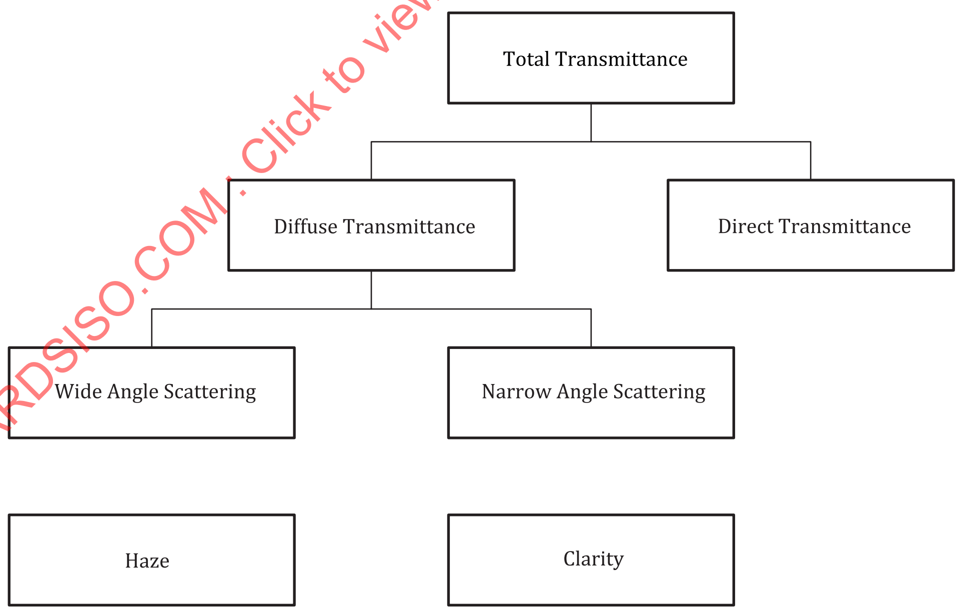


Figure 50 — List of transmittance properties

6.1.5.2 Haze (transmission haze)

Haze is defined as the amount of light that is subject to wide-angle scattering (at angles greater than 2,5° from normal) (ASTM D1003 or ISO 13468-1) (see Figure 51).

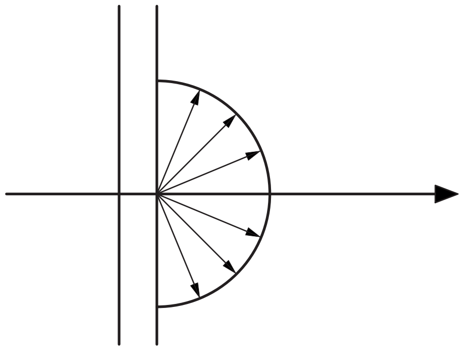


Figure 51 — Haze

6.1.5.3 Clarity (transmission clarity)

Clarity is defined as the amount of light that is subject to narrow-angle scattering (at angles less than 2,5° from normal) (ISO 13468-2) (see Figure 52).

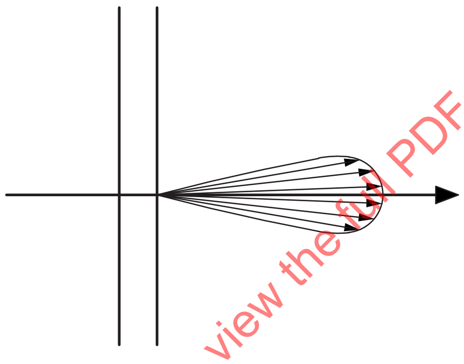


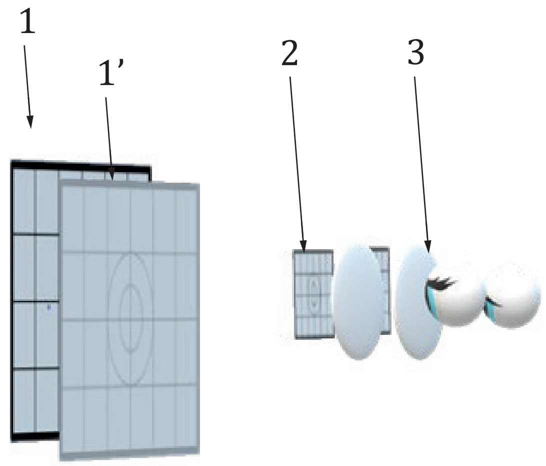
Figure 52 — Clarity

6.1.5.4 Spectral transmittance

Spectral transmittance is the property whereby the transmittance depends on spectral differences. There are two types of spectral transmittance: spectral hemispherical transmittance *Tν* including all incident light, and spectral directional transmittance *TΩ,ν*.

6.1.5.5 Double image

Double images or double vision is the simultaneous perception of two images of a single object that would be displaced horizontally, vertically, diagonally or rotationally in relation to each other (see Figure 53).



Key

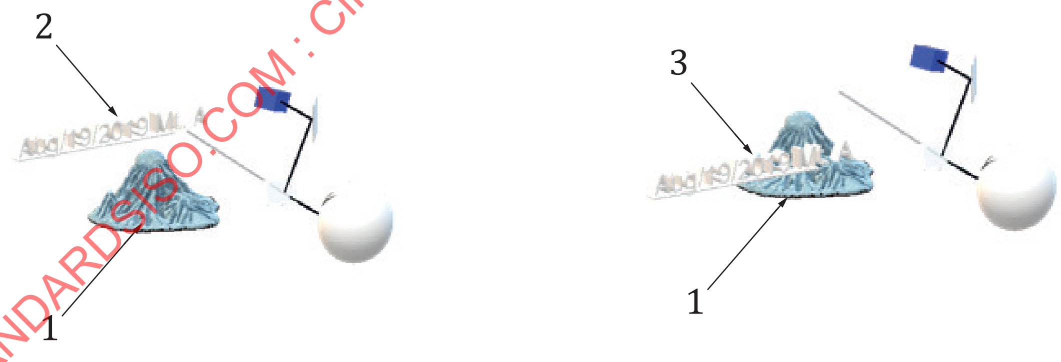
1 virtual image
1' mislocated virtual image
2 displays with real images
3 convex lenses

Figure 53 — Double images

6.1.6 For AR

6.1.6.1 AR displacement

AR displacement is the misallocation of a virtual image (object). For whatever reason, the virtual image is somehow placed in an unintended location (see Figure 54).



a) designed position of virtual image

b) mislocated virtual image

Key

1 real object
2 virtual image at intended location
3 virtual image at misallocated location

Figure 54 — AR displacement

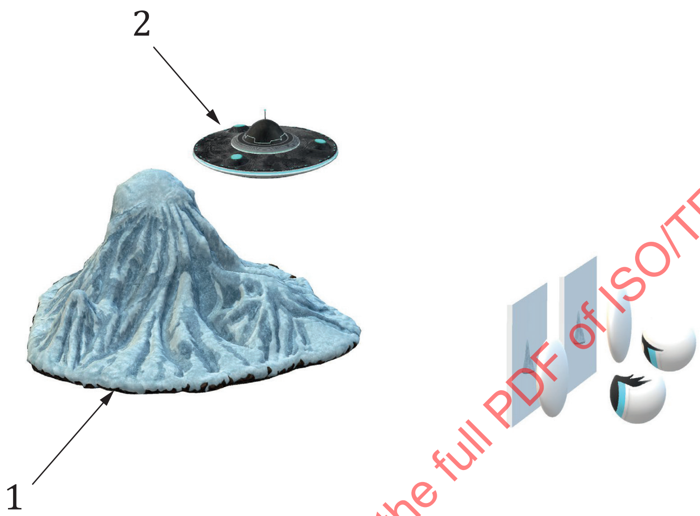
6.1.7 For AR, video see-through properties

6.1.7.1 See through latency

See-through latency is a certain delay in presenting images through the video system, camera, video processing system and displays.

6.1.7.2 Alignment (video see-through)

Alignment involves aligning the video see-through image and the computer-generated image (see Figure 55).



Key

1 real object, captured by camera, shown by displays

2 virtual image at intended location

Figure 55 — Alignment, AR video see through

Note The resolution of the virtual image might be an issue for AR HMDs and video-see-through HMDs.

6.1.8 For light field display

6.1.8.1 Focus depth

The focus depth is the range in which the viewer can see a clear image without needing an adjustment (see Figure 56).

