TECHNICAL REPORT

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Ergonomics of human-system interaction —

Part 331: **Optical characteristics of autostereoscopic displays**

Ergonomie de l'interaction homme-système —

Partie 331: Caractéristiques optiques des écrans autostéréoscopiques

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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 9241-331 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

ISO 9241 consists of the following parts, under the general title *Ergonomic requirements for office work with visual display terminals (VDTs)*:

— *Part 1: General introduction*

— *Part 2: Guidance on task requirements*

— *Part 4: Keyboard requirements*

— *Part 5: Workstation layout and postural requirements*

— *Part 6: Guidance on the work environment*

— *Part 9: Requirements for non-keyboard input devices*

— *Part 11: Guidance on usability*

— *Part 12: Presentation of information*

— *Part 13: User guidance*

— *Part 14: Menu dialogues*

— *Part 15: Command dialogues*

— *Part 16: Direct manipulation dialogues*

ISO 9241 also consists of the following parts, under the general title *Ergonomics of human-system interaction*:

- *Part 20: Accessibility guidelines for information/communication technology (ICT) equipment and services*
- *Part 100: Introduction to standards related to software ergonomics* [Technical Report]
- *Part 110: Dialogue principles*
- *Part 129: Guidance on software individualization*
- *Part 143: Forms*
- *Part 151: Guidance on World Wide Web user interfaces*
- *Part 154: Interactive voice response (IVR) applications*
- *Part 171: Guidance on software accessibility*
- *Part 210: Human-centred design for interactive systems*
- *Part 300: Introduction to electronic visual display requirements*
- *Part 302: Terminology for electronic visual displays*
- *Part 303: Requirements for electronic visual displays*
- *Part 304: User performance test methods for electronic visual displays*
- *Part 305: Optical laboratory test methods for electronic visual displays*
- *Part 306: Field assessment methods for electronic visual displays*
- *Part 307: Analysis and compliance test methods for electronic visual displays*
- *Part 308: Surface-conduction electron-emitter displays (SED)* [Technical Report]
- *Part 309: Organic light-emitting diode (OLED) displays* [Technical Report]
- *Part 310: Visibility, aesthetics and ergonomics of pixel defects* [Technical Report]
- *Part 331: Optical characteristics of autostereoscopic displays* [Technical Report]
- *Part 400: Principles and requirements for physical input devices*
- *Part 410: Design criteria for physical input devices*
- *Part 411: Evaluation methods for the design of physical input devices* [Technical Specification]
- *Part 420: Selection of physical input devices*
- *Part 910: Framework for tactile and haptic interaction*
- *Part 920: Guidance on tactile and haptic interactions*

User-interface elements, requirements, analysis and compliance test methods for the reduction of photosensitive seizures, ergonomic requirements for the reduction of visual fatigue from stereoscopic images, and the evaluation of tactile and haptic interactions are to form the subjects of future Parts 161, 391, 392 and 940.

Introduction

Recent developments in display technologies have made it possible to render highly realistic content on high-resolution colour displays. The developments include advanced 3D display technologies such as autostereoscopic displays. The new 3D displays extend the capabilities of applications by giving the user more-realistic-than-ever perception in various application fields. This is valid not only in the field of leisure but also in the fields of business and education, and in medical applications.

Nevertheless, 3D displays have display-specific characteristics originating from the basic principles of the image formation applied for the different 3D display designs. Among negative characteristics are imperfections that affect the visual quality of the displayed content and the visual experience of the users. These imperfections can induce visual fatigue for the users, which is one of the image safety issues described in IWA 3:2005. Nevertheless, it is important for the end user to be able to enjoy of the benefits of the 3D display without suffering any undesirable biomedical effects. It is therefore necessary that a standardized methodology be established which characterizes and validates technologies in order to ensure the visual quality of the displays and the rendered content. The development of such a methodology has to be based on the human perception and performance in the context of stereoscopic viewing.

The negative characteristics, by nature, originate from both 3D displays and 3D image content. In this part of ISO 9241, however, attention is focussed only on 3D display, for simplicity of discussion and as a first step.

In ISO 9241-303, performance objectives are described for virtual head-mounted displays (HMDs). This is closely related to autostereoscopic displays, but not directly applicable to them.

Considering the growing use of autostereoscopic displays, and the need for a methodology for their characterization in order to reduce visual fatigue caused by them, this Technical Report presents basic principles for related technologies, as well as optical measurement methods required for the characterization of the current technologies and for a future International Standard on the subject.

Since this Technical Report deals with display technologies that are in continual development, its content will be updated if and as necessary. It includes no content intended for regulatory use.

Ergonomics of human-system interaction —

Part 331: Optical characteristics of autostereoscopic displays

1 Scope

This part of ISO 9241 establishes an ergonomic point of view for the optical properties of autostereoscopic displays (ASDs), with the aim of reducing visual fatigue caused by stereoscopic images on those displays. It gives terminology, performance characteristics and optical measurement methods for ASDs.

It is applicable to spatially interlaced autostereoscopic displays (two-view, multi-view and integral displays) of the transmissive and emissive types. These can be implemented by flat-panel displays, projection displays, etc.

2 Terms and definitions

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

2.1 General terms

2.1.1
3D display
display device or system including a special functionality for enabling depth perception

2.1.2
stereoscopic display
3D display where depth perception is induced by binocular parallax

NOTE 1 People perceive depth from the retinal disparity provided by binocular parallax.

NOTE 2 Stereoscopic displays include stereoscopic displays requiring glasses, stereoscopic HMDs and autostereoscopic displays.

NOTE 3 See ISO 9241-302:2008, 3.5.5, *binocular display device*.

2.1.3
autostereoscopic display
ASD
stereoscopic display that requires neither viewing aids such as special glasses nor head-mounted apparatus

NOTE Autostereoscopic displays includes two-view displays, multi-view displays and integral displays, as well as other types of display not discussed in this part of ISO 9241, such as holographic displays and volumetric displays.

2.1.4
two-view display
two-view autostereoscopic display
autostereoscopic display that creates two monocular views with which the left and right stereoscopic images are coupled

2.1.5
multi-view display
multi-view autostereoscopic display
autostereoscopic display that creates more than two monocular views with which the stereoscopic images are coupled

NOTE 1 It becomes an autostereoscopic display when the number of stereoscopic images is increased from two to more than two.

NOTE 2 Principally, one of multiple stereoscopic images corresponds to one of multiple stereoscopic views, yet not necessarily excluding one-to-multi correspondence.

2.1.6
integral display
integral autostereoscopic display
autostereoscopic display that is intended to optically reproduce three-dimensional objects in space

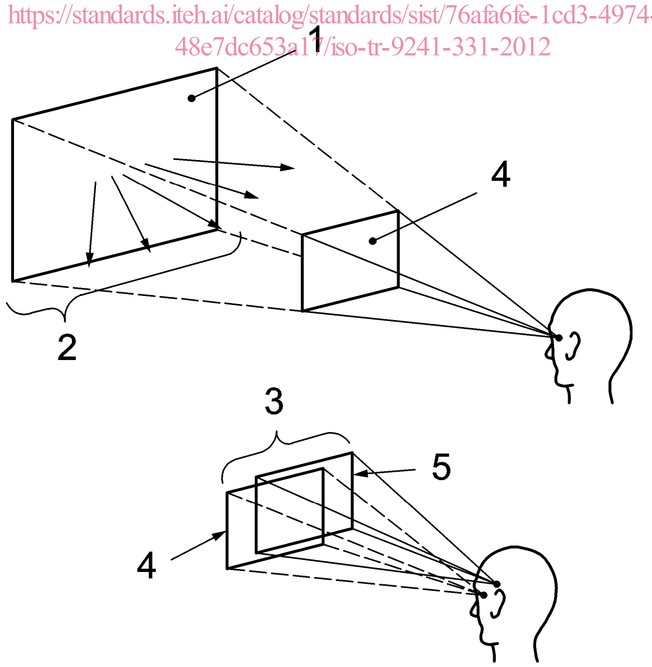
NOTE Since, at present, it is not easy to make the optical reproduction perfect, integral displays are not necessarily free from such factors of undesirable biomedical effect as accommodation-vergence inconsistency (see 3.7, 4.1).

2.1.7
stereoscopic images
set of images with parallax shown on a stereoscopic display

NOTE See 2.1.8.

2.1.8
stereoscopic views
pair of sights provided by a stereoscopic display, which induce stereopsis

NOTE See Figure 1.



Key

1 autostereoscopic display
2 stereoscopic images
3 stereoscopic views
4 monocular view (left eye)
5 monocular view (right eye)

Figure 1 — Relation between stereoscopic images, stereoscopic views and monocular view

2.1.9
monocular view
one stereoscopic view

NOTE See 2.1.8.

2.1.10
number of views
number of monocular views with which stereoscopic images are coupled

2.2 Human factors

2.2.1
binocular parallax
apparent difference in the direction of a point as seen separately by one eye and by the other, while the head remains in a fixed position

NOTE 1 See IWA 3:2005, 2.15.

NOTE 2 Binocular parallax is equivalent to the optic angle between the visual axes of both eyes, when they are fixated to a single point.

2.2.2
visual fatigue
eyestrain or asthenopia, which shows a wide range of visual symptoms, including tiredness, headache and soreness of the eyes, caused by watching images in a visual display

NOTE 1 Adapted from IWA 3:2005, 2.13.

NOTE 2 See also ISO 9241-302:2008, 3.5.3.

2.2.3
accommodation
adjustment of the optics of an eye to keep an object in focus on the retina as its distance from the eye varies

[SOURCE: ISO 9241-302:2008, 3.5.1, modified — the Note to the definition has not been included.]

NOTE Adapted from IWA 3:2005, 2.18.

2.2.4
convergence
turning inward of the lines of sight toward each other as the object of fixation moves toward the observer

[SOURCE: ISO 9241-302:2008, 3.5.10]

NOTE See also IWA 3:2005, 2.19.

2.3 Performance characteristics

2.3.1
3D crosstalk
leakage of an unwanted image data to each eye

2.3.2
interocular crosstalk
leakage of the stereoscopic image(s) from one eye to the other

2.3.3
interocular luminance difference
difference in luminance between stereoscopic views

2.3.4
interocular chromaticity difference
difference in chromaticity between stereoscopic views

2.3.5
interocular contrast difference
difference in contrast between stereoscopic views

2.3.6
3D moiré
periodical irregularity of luminance or chromaticity in space or angular directions on a 3D display

2.3.7
pseudoscopic images
pseudo-stereoscopic images
set of images with inverted parallax shown on a stereoscopic display

2.3.8
3D image resolution
spatial resolution of the image with depth shown on a stereoscopic display

NOTE The term "spatial resolution" refers to horizontal and vertical resolution, as shown in the ISO 9241 300 series.

2.3.9
qualified viewing space
QVS
⟨autostereoscopic displays⟩ space for the eye in which image(s) is observed at an acceptable level of visual fatigue

NOTE 1 See also ISO 9241-302, 3.5.42.

NOTE 2 QVS is defined separately for each eye as the measurement result is unambiguous and equally valid for all observers, whereas the measured QBVS and QSVS results as such are only valid for people with average eye separation.

NOTE 3 This term still needs discussion, because "monocular" viewing space is insufficient for determining the characteristics of autostereoscopic displays that require "binocular" viewing.

2.3.10
qualified binocular viewing space
QBVS
space in which images on a stereoscopic display are observed by both eyes at an acceptable level of visual fatigue

NOTE 1 This term is based on the concept that there should be space where visual fatigue caused by pseudo-stereoscopy is small enough.

NOTE 2 This term still needs discussion, because it is not clear whether there can exist a space larger than QSVS, which would still satisfy the visual fatigue requirements.

2.3.11
qualified stereoscopic viewing space
QSVS
space in which images on a stereoscopic display induce stereopsis at an acceptable level of visual fatigue

NOTE This term is based on the concept that there should be space where visual fatigue caused by stereoscopic images is small enough.

3 Autostereoscopic display technologies

3.1 General

In this clause, technological features of autostereoscopic displays are described. Firstly, information for people to perceive depth provided by autostereoscopic displays is explained. This is essential for understanding the basics of autostereoscopic display technologies. Secondly, the autostereoscopic displays are classified according to their technological aspects. Three different display technologies are presented based on their principles, structures and features. Finally, to establish optical measurement methods for evaluating visual fatigue caused by these autostereoscopic displays, the related matters are discussed in the light of both, ergonomics and technologies.

3.2 Cues for depth perception

People usually perceive the three-dimensional visual world based on retinal images of two eyes. The cues for such depth perception are not only binocular cues but also monocular cues. These cues are shown in Table 1.

Table 1 — Classification of depth cues

	Binocular	**Monocular**
Absolute depth	Convergence/Binocular parallax	Accommodation Motion parallax
Relative depth	Binocular disparity	Motion disparity Pictorial depth cues [a]

[a] Pictorial depth cues

Geometrical perspective

Relative/familiar size

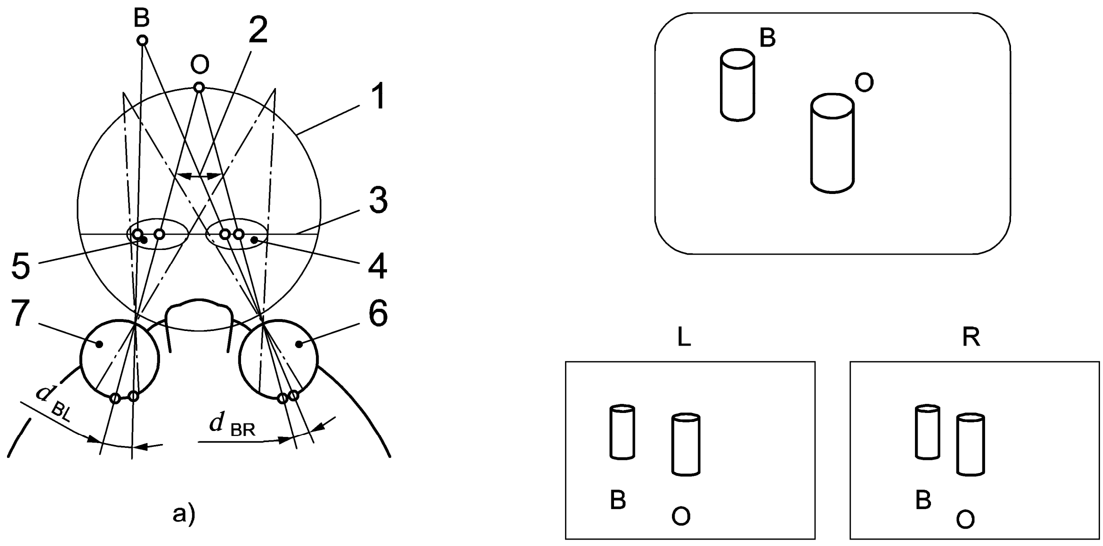
Shading/Shadow

Occlusion

Texture

Aerial perspective, etc.

For autostereoscopic displays, the device itself provides binocular and monocular parallax as absolute distance cues, and binocular and monocular disparity as relative depth cues. Binocular parallax is presented as interocular differences in apparent direction of a target, while binocular disparity is presented as in relative position of retinal images of two different objects. Both concepts are shown in Figure 2.



a) b)

Key

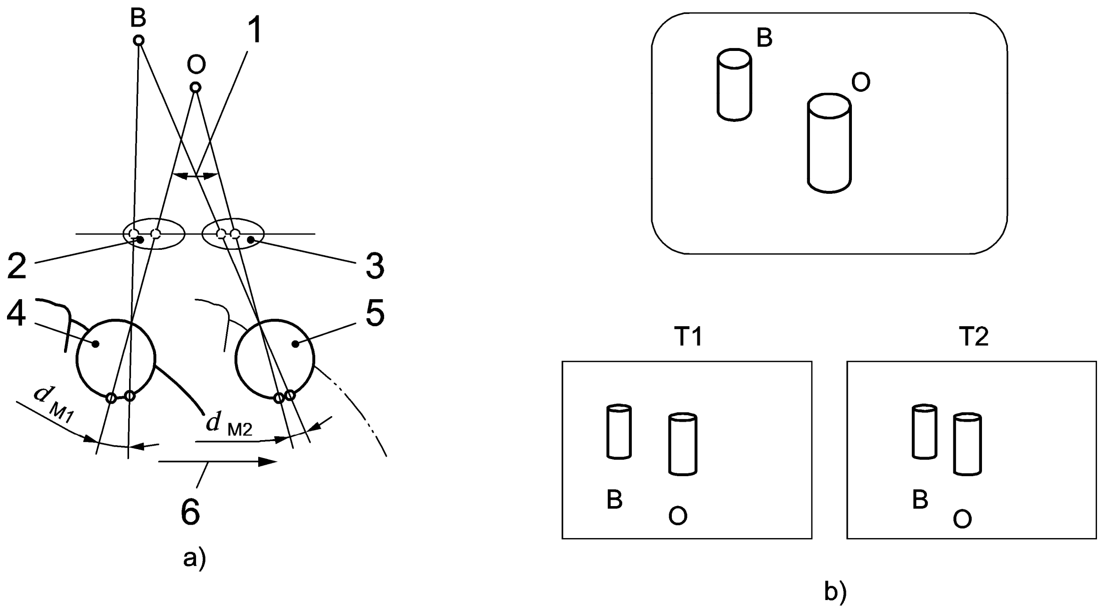
1	Vieth Muller circle	5	image for left eye	O	fixated object
2	binocular parallax θ_{LOR}	6	right eye	L	left eye image
3	display surface	7	left eye	R	right eye image
4	image for right eye	B	target object		$d_{BR} - d_{BL}$ = binocular disparity

Figure 2 — Binocular parallax and disparity

If an object, (e.g. object “O” in Figure 2a), is fixated by the two eyes, the apparent direction of the object relative to the right eye is different from the direction relative to the left eye. This difference is called binocular parallax. Moreover in Figure 2a, when the other object, such as “B”, exist, the apparent gap between the two objects “O” and “B” is different in the views of the left and the right eye (see Figure 2b). This difference originates in binocular parallax. This difference, binocular disparity, is described as the difference in angle between d_{BL} and d_{BR} as shown in Figure 2.

In Figure 2, the circle connecting three points, two nodes of the eyes and the fixation point “O”, is the Vieth-Müller circle, which is the theoretical horopter. Any point on the horopter builds up its retinal image on corresponding points of the two retinae, thus are viewed single. Therefore, none of the points on the circle produce binocular disparity with each other including the fixated point “O”. The actual horopter, or empirical horopter, has been measured, and is known as slightly different in its shape from the theoretical horopter.

Motion parallax and disparity are caused when different images are observed from different positions. As the head moves from left to right, the absolute and relative positions of object images change, which creates motion parallax and disparity, respectively, as shown in Figure 3.



Key

1	motion parallax θ_{M12}	4	right eye position at time T1	B	target object
2	image position at time T1	5	right eye position at time T2	O	fixated object
3	image position at time T2	6	head movement		$d_{M1} - d_{M2}$ = motion disparity

Figure 3 — Motion parallax and disparity

When an object (e.g. object “O” in Figure 3) is fixated by a single eye during head movements, the apparent direction of the object relative to the eye varies depending on the eye’s position. This variation of apparent direction is called motion parallax. Moreover, when the two objects, “O” and “B” in Figure 3, are seen during head movements, the apparent adjacency changes, for example, between the views at time T1 and time T2 (see Figure 3). This change is produced because of motion parallax. This difference is described as the difference in angle between d_{M1} and d_{M2}, or motion disparity.

The term “motion parallax” is used for motion disparity. For example, motion parallax is defined as the relative movement of images across the retina resulting from movement of the observer.

3.3 Stereoscopic display classification

A stereoscopic display is defined as a 3D display, for which depth perception is induced by binocular parallax. The binocular parallax provides disparity between retinal images, which induces stereopsis.

Stereoscopic displays can be classified into three types:

- autostereoscopic displays;
- stereoscopic Head-Mounted Displays (HMDs); and
- stereoscopic displays requiring glasses.

Stereoscopic viewing has traditionally required users to wear special viewing devices, like glasses with polarizing or colour filters. In contrast, autostereoscopic displays do not require special viewing devices. Whether glasses are required or not is an important factor in ergonomics. The visual factors of HMDs are also different from those of autostereoscopic displays or stereoscopic displays using glasses. This is the reason why these three display types are classified in three separate categories. In this part of ISO 9241, only autostereoscopic displays are covered.

Until now, many types of autostereoscopic displays have been developed and various concepts of classification have been proposed according to their related factors. Figure 4 shows the classification of autostereoscopic displays in this part of ISO 9241. In this taxonomy, ergonomics aspects of autostereoscopic display hardware are the basis for the classification. There exist other stereoscopic display technologies, that are not shown in this taxonomy – some of which are not yet even known.

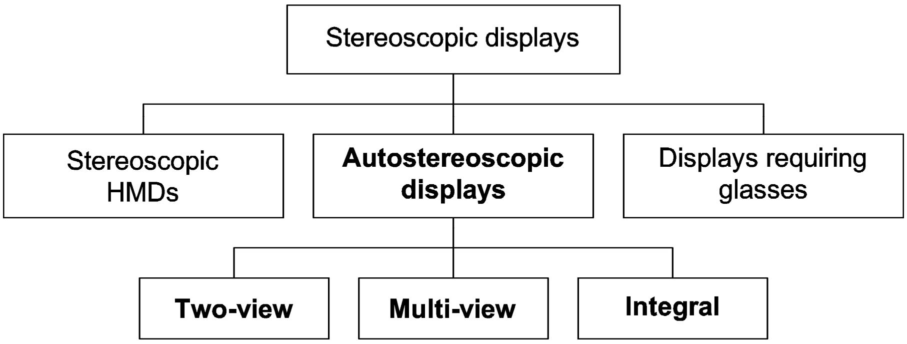


Figure 4 — Taxonomy of stereoscopic displays

Autostereoscopic displays can be classified into two-view, multi-view and integral displays according to the viewpoints of visual ergonomics. In this classification, the integral display belongs to autostereoscopic displays, as it fulfils the definition of autostereoscopic displays.

Autostereoscopic displays could also be classified into spatially and temporally interlaced types. Human factors for the spatially interlaced type are generally different from those for the temporally interlaced type. Compared to the spatially interlaced type, the temporally interlaced type can have discriminative characteristics, such as temporal changes in luminance and colour, and flicker, which can affect the visual quality of the displayed content and the visual experience of the users.

An autostereoscopic display is able to produce, at least, two different images which are perceived by the two eyes of the user, respectively. Those images are used for producing binocular parallax and disparity to simulate depth among the observer and objects. Examples of producing different images are shown in Figure 2 and Figure 3.

For the multi-view and integral displays, lateral head movements parallel to display surface can derive parallax images, which simulate motion parallax and disparity also for simulating depth among observer and objects.

Autostereoscopic displays have some principle differences in their optical characteristics compared to conventional two-dimensional (2D) displays:

— Binocular difference;

  — An autostereoscopic display is able to show a different image for each eye, while a 2D display is not.

— Directional non-uniformity;

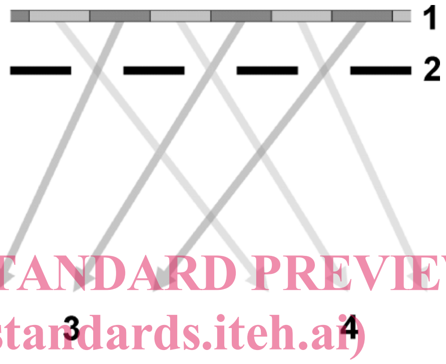
  — An autostereoscopic display provides different images in different angular directions, and thus, angular directional characteristics are not made to be uniform. For a 2D display, angular uniformity is tried to be maintained.

— Lateral non-uniformity.

  — In some cases, in order to improve some of the characteristics, all spatial screen locations are not made to have the same characteristics.

Some of the autostereoscopic displays can provide not only horizontal but also vertical parallax/disparity. In this part of ISO 9241, mainly one-dimensional parallax in the horizontal direction is discussed.

A typical spatially interlaced autostereoscopic display consists of a base 2D display panel and some additional (electro-)optical components for controlling the light output angles, such as parallax barrier or lenticular sheet. In spatially interlaced displays, the displayed picture elements, pixels or sub-pixels, are multiplexed into two or more sections with slightly different stereoscopic views of the displayed content. The parallax barrier or lenticular structure conveys the information to the space in front of the display. A parallax barrier has an array of light blocking opaque barriers, each slit between the barriers corresponding to each certain pixel group. In lenticular type autostereoscopic displays, semi-cylindrical lenses are used instead of the slits to lessen the absorption of display illumination. In addition, many other possibilities exist for the creation of a two-view spatially interlaced display. When the two eyes of the user receive the binocular parallax resulting from these arrangements, depth perception is induced. The basic principle of the parallax barrier type autostereoscopic display is illustrated in Figure 5. In this figure, the arrow represents the main direction of light from each pixel. For simplicity, descriptions and drawing of autostereoscopic displays henceforth refer to the parallax barrier type autostereoscopic display.



Key

1 display (sub)pixels
2 parallax barrier
3 light rays from pixels for the left eye
4 light rays from pixels for the right eye

Figure 5 — Conceptual illustration of basic display technology in a two-view display

Parallax barrier or lenticular array structures are necessary to be aligned with the display pixels. Content of the display pixels or sub-pixels should be interlaced according to these structures. Vertical structures typically result in reduced observed resolution in horizontal direction. Slanted or step barrier structures can divide the resolution drop both in horizontal and vertical direction.

An autostereoscopic display can generally be used as a 2D display by showing images without binocular parallax. Some autostereoscopic displays have a 2D/3D selection switch by which they are turned to 2D mode, if needed.

3.4 Two-view (autostereoscopic) display

3.4.1 Definition and principle

A two-view display is defined as an autostereoscopic display, that creates two monocular views with which the left and right stereoscopic images are coupled. On a two-view display, left and right images are shown. The left part of stereoscopic images is observed by the left eye, while the right part is observed by the right eye, as illustrated in Figure 6. As a result, binocular parallax for depth perception can be created.

