



IEEE Standard for the Quality of Experience (QoE) and Visual Comfort Assessments of Three-Dimensional (3D) Contents Based on Psychophysical Studies

IEEE Computer Society

Standards Activities Board Standards Committee

IEEE Std 3333.1.1™-2024
(Revision of IEEE Std 3333.1.1™-2015)



STANDARDS

IEEE Std 3333.1.1™-2024

(Revision of IEEE Std 3333.1.1™-2015)

IEEE Standard for the Quality of Experience (QoE) and Visual Comfort Assessments of Three-Dimensional (3D) Contents Based on Psychophysical Studies

Developed by the

Standards Activities Board Standards Committee
of the
IEEE Computer Society

Approved 15 February 2024

IEEE SA Standards Board

This is a Redline document produced by Accuris.

Redlines are designed to save time and improve productivity by using the latest software technology to find and highlight document changes from one edition to the next. It includes a full-text version of the new document, plus an indication of changes from the previous version.

Because it may not be technically possible to capture all changes accurately, it is recommended that users consult previous editions as appropriate. In all cases, only the current base version of this publication is to be considered the official document. This Redline is produced solely by Accuris. The publisher has not prepared this Redline and is not responsible for its accuracy.

Contact:

<https://store accuristech.com/pages/contact.html>

Redline Processing Notes:

1. ~~Red Text~~ - Red strikethrough text denotes deletions.
2. Blue Text - Blue underlined text denotes modifications and additions.

Abstract: As the supply and demand for 3D technologies grows, the development of accurate quality assessment techniques is necessary to develop the industries of the 3D display devices and signal processing engines. Underlying principles and statistical characteristics of 3D contents based on human visual system (HVS) are described in this standard. In addition, the reliable 3D subjective assessment methodology that covers the characteristics of human perception, display mechanism, and viewing environment is introduced in this document.

Keywords: accommodation and vergence conflict, foveation, human visual system, HVS, IEEE 3333.1.1™, quality assessment, quality of experience, QoE, saliency detection, stereoscopic, stereoscopic display, subjective assessment, visual contents analysis, visual (dis)comfort

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2024 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 17 May 2024. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 979-8-8557-0739-7 STD26939
Print: ISBN 979-8-8557-0740-3 STDPD26939

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <https://www.ieee.org/about/corporate/governance/p9-26.html>.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (<https://standards.ieee.org/ipr/disclaimers.html>), appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents are developed within IEEE Societies and subcommittees of IEEE Standards Association (IEEE SA) Board of Governors. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers are not necessarily members of IEEE or IEEE SA and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning this standard, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. IEEE Standards documents do not guarantee safety, security, health, or environmental protection, or guarantee against interference with or from other devices or networks. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. IEEE Standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity, nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon their own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: THE NEED TO PROCURE SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus balloting process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE is the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that the presenter's views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group. Statements made by volunteers may not represent the formal position of their employer(s) or affiliation(s).

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, consulting information, or advice pertaining to IEEE Standards documents.**

Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its Societies and subcommittees of the IEEE SA Board of Governors are not able to provide an instant response to comments, or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in evaluating comments or in revisions to an IEEE standard is welcome to join the relevant IEEE working group. You can indicate interest in a working group using the Interests tab in the Manage Profile & Interests area of the [IEEE SA myProject system](#).¹ An IEEE Account is needed to access the application.

Comments on standards should be submitted using the [Contact Us](#) form.²

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not constitute compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and

¹ Available at: <https://development.standards.ieee.org/myproject-web/public/view.html#landing>.

² Available at: <https://standards.ieee.org/content/ieee-standards/en/about/contact/index.html>.

adoption by public authorities and private users, neither IEEE nor its licensors waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate licensing fees, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400; <https://www.copyright.com/>. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit [IEEE Xplore](#) or [contact IEEE](#).³ For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the [IEEE SA Website](#).⁴ Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in [IEEE Xplore](#). Users are encouraged to periodically check for errata.

Patents

IEEE standards are developed in compliance with the [IEEE SA Patent Policy](#).⁵

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at <https://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

³ Available at: <https://ieeexplore.ieee.org/browse/standards/collection/ieee>.

⁴ Available at: <https://standards.ieee.org/standard/index.html>.

⁵ Available at: <https://standards.ieee.org/about/sasb/patcom/materials.html>.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

IMPORTANT NOTICE

Technologies, application of technologies, and recommended procedures in various industries evolve over time. The IEEE standards development process allows participants to review developments in industries, technologies, and practices, and to determine what, if any, updates should be made to the IEEE standard. During this evolution, the technologies and recommendations in IEEE standards may be implemented in ways not foreseen during the standard's development. IEEE standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

Participants

At the time this IEEE standard was completed, the Human Factors for Visual Experiences Working Group had the following membership:

Sanghoon Lee, *Chair*
Patrick Le Callet, *Vice Chair*

Sungho Cho
Seonghwa Choi
Ricky Christanto
Seunghan Han
Huychan Jung
Sangkwon Jung

Jaekyung Kim
Jinwoo Kim
Seongyong Kim
Taewan Kim
Jaekeun Kwak

Jaeun Lee
Jongmuk Lee
Sangeun Lee
Jing Li
Ahn-Duc Nguyen
An Ping

The following members of the individual Standards Association balloting group voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Robert Aiello
Pin Chang
Werner Hoelzl

Piotr Karocki
Daozhuang Lin
R. K. Rannow

Dorothy Stanley
Lisa Ward
Yu Yuan

When the IEEE SA Standards Board approved this standard on 15 February 2024, it had the following membership:

David J. Law, *Chair*
Vacant Position, *Vice Chair*
Gary Hoffman, *Past Chair*
Alpesh Shah, *Secretary*

Sara R. Biyabani
Ted Burse
Stephen Dukes
Doug Edwards
J. Travis Griffith
Guido R. Hiertz
Ronald W. Hotchkiss
Hao Hu

Yousef Kimiagar
Joseph L. Koepfinger*
Howard Li
Xiaohui Liu
John Haiying Lu
Kevin W. Lu
Hiroshi Mano

Paul Nikolich
Robby Robson
Mark Siira
Lei Wang
F. Keith Waters
Sha Wei
Philip B. Winston
Don Wright

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 3333.1.1-2024, IEEE Standard for the Quality of Experience (QoE) and Visual Comfort Assessments of Three-Dimensional (3D) Contents Based on Psychophysical Studies.

This standard is specifically written to high-end three-dimensional (3D) service purveyors, 3D display makers and the 3D digital cinema and gaming industry. This standard establishes methods of visual discomfort and quality of experience (QoE) assessments of 3D contents based on psychophysical studies. These key factors are constructed in conjunction with the visual factors, to quantify discomfort and QoE degradation of 3D contents.

Contents

1. Overview	10
1.1 Scope	10
1.2 Word usage	10
2. Normative references	10
3. Definitions, acronyms, and abbreviations	11
3.1 Definitions	11
3.2 Acronyms and abbreviations	13
4. Ergonomic requirements and recommendations	14
4.1 General	14
4.2 Visual saliency prediction	14
4.3 Visual contents analysis	14
4.4 Subjective assessment	14
5. Visual saliency prediction	14
5.1 General	14
5.2 Human visual system	14
5.3 Saliency prediction	16
6. Visual contents analysis	22
6.1 General	22
6.2 Human visual system	22
6.3 Spatial characteristics of 3D contents	23
6.4 Temporal characteristics of 3D contents	26
7. Subjective assessment	32
7.1 General	32
7.2 Display device for subjective assessment	32
7.3 Continuous assessment methodology	32
7.4 Paired comparison methodology	36
8. Objective assessment	40
8.1 General	40
8.2 Deep visual discomfort predictor (DeepVDP) for stereoscopic 3D images	40
Annex A (informative) Bibliography	44

IEEE Standard for the Quality of Experience (QoE) and Visual-Comfort Assessments of Three-Dimensional (3D) Contents Based on Psychophysical Studies

~~IMPORTANT NOTICE: IEEE Standards documents are not intended to ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.~~

~~This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading "Important Notice" or "Important Notices and Disclaimers Concerning IEEE Documents." They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.~~

1. Overview

1.1 Scope

This standard establishes various traditional and deep learning-based methods for visual saliency prediction, visual contents analysis, and subjective assessments ~~assessment~~ for quantifying the visual discomfort and quality of experience (QoE) of ~~three-dimensional(3D)~~ image and video.

1.2 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

⁶ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ITU-P.910, Subjective video quality assessment methods for multimedia applications.⁸

ITU-R BT.500-13₁ ÷ Methodology for the subjective assessment of the quality of television pictures.¹

ITU-R BT.1438₁ ÷ Subjective assessment of stereoscopic television pictures.

ITU-R BT.2021₁ ÷ Subjective methods for the assessment of stereoscopic 3DTV systems.

~~ITU-T P.910: Subjective video quality assessment methods for multimedia applications.~~

~~Stereoscopic (3D Imaging) Database.²~~

⁸ ITU-T publications are available from the International Telecommunications Union (<https://www.itu.int/>).

¹ ~~ITU publications are available from Publication Sales, International Telecommunication Union, Place des Nations, 1211 Geneva 20, Switzerland (<http://www.itu.int/>).~~

² ~~Available at <http://grouper.ieee.org/groups/3dhf>~~

3. Definitions, acronyms, and abbreviations~~, and acronyms~~

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.^{9,3}

accommodation: The process by which the vertebrate eye changes optical power to maintain a clear image or focus on an object as its distance varies.

angular disparity: The angle differences in image location of an object seen by both human eyes, resulting from the eye movements~~by both human eyes.~~

auto-stereoscopic display: A display device capable of experiencing ~~providing~~ depth perception to human viewers without the use of glasses.

ciliary muscle: The ring of striated smooth muscles in the human eye's vascular layer that control ~~controls~~ accommodation according to viewing distance.

comfortable viewing zone: The range of object or viewer position where a viewer can watch a scene without any discomfort.-

crosstalk: The incomplete isolation of the left and right image, such that ~~causes~~ one image leaks ~~leak~~ into the other image.

crystalline lens: The lens of a human eye composed of fibers that come from epithelial cells.

diplopia: The subjective complaint of seeing two images when viewing one object.-

⁹IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

³~~IEEE Standards Dictionary Online subscription is available at: http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.~~

disparity contrast: The absolute difference ~~between~~ values in a target disparity value with neighbor disparity values within the same window.

disparity gradient: The absolute values of the derivate to the disparity map on ~~the~~ x- and y-axis.

extra-ocular muscles: The six muscles (~~in each eye~~) that are expanded or contracted for eye movements.

fovea: The part of the eye located in the center of the macular area of the retina.

horopter: The locus of points in space that yield single vision.

human visual system: The part of the central nervous system that gives organisms the ability to process visual detail, as well as enabling ~~and enables~~ the formation of several non-image photo response functions.

lab color space: The color-opponent space with dimension lightness and two-color opponent dimensions (a and b) based on nonlinearly compressed CIE XYZ color ~~space~~ coordinates.^{10,11}

luminance contrast: The absolute difference ~~between~~ values in a target luminance value with neighbor luminance values within the same window.

luminance gradient: The absolute values of the derivative ~~derivate~~ to the disparity map on ~~the~~ x- and y -axis ~~axes~~.

mean opinion score: In a subjective quality assessment, the average of all subjects rating scores of quality of experience.

negative disparity: The condition when ~~the angular disparity value is smaller than zero because~~ the corresponding object is located in front of the 3D display and the angular display value is smaller than zero.

¹⁰ CIE X, Y and Z are the CIE 1931 tri-stimulus values [B8].

¹¹ The numbers in brackets correspond to those of the bibliography in Annex A.

Panum's fusional area: The small region ~~on~~ either side of the horopter where objects will still be seen as fused. ~~This region in space corresponding to an area~~ on the retina is referred to as Panum's fusional area ~~or Panum's area~~.

photoreceptor: ~~The~~ Retinal cells responsible for ~~the~~ detection of light.

positive disparity: The condition when ~~the angular disparity value is larger than zero because~~ the corresponding object is located behind of the 3D display and the angular display value is larger than zero.

probability mass function: ~~In statistics, this is~~ The function that defines ~~gives~~ the probability that a discrete random variable is exactly equal to some value.

quality assessment: The evaluation of a quality of the service or product to determine the performance in relation to set standards.

quality of experience: The degree of delight or annoyance of the user of an application or service. It results resulting from the fulfillment of his or her expectations with respect to the utility and/or enjoyment of the application or service given ~~in light of~~ the user's personality and current state.

retina: The sensitive layer of tissue at the back of the eye that receives sensory images.

~~**shear distortion:** A different kind of distortion caused when a viewer moves.~~

skewness: ~~In statistics, this is~~ The degree to which a statistical distribution is not in equilibrium around the average, ~~an exactly symmetrical distribution having a value of zero~~.

stereoscopic display: A device capable of experiencing depth perception to viewers by means of stereopsis for binocular parallax.

subjective assessment: An assessment of quality or visual discomfort where there is no pre-established objective measure or standard and is thus based solely on the opinion of the evaluator or a group of observers.

support vector machine: A type of machine learning algorithm that performs supervised learning for classification or regression of data groups. ~~this is a supervised learning model with associated learning algorithms.~~

system crosstalk: The degree of the leaking image from the other image that is determined by the display itself.

vergence: Simultaneous movements of both eyes in opposite directions to obtain or maintain single binocular vision clearly.

visual cortex: The part of the cerebral cortex that is responsible for processing visual information.

viewing distance: The distance between the viewer and display.

~~**visual (dis)comfort:** The state of mind that expresses (dis)satisfaction with the visual environment. In other words, visual discomfort is a subjective sensation that accompanies physiological changes, in this case the stress of viewing 3D content. As a subjective sensation, it can be measured by asking the viewer to report its level. The negative sensation usually declines rapidly when the human observer gazes at a comfortable scenario or closes his eyes.~~

~~**visual cortex:** The part of the cerebral cortex responsible for processing visual information.~~

~~**visual fatigue:** A decrease in performance of the human vision system due to a physiological change. This change shall be diagnosed by medical personnel using various symptoms that can either be subjectively reported by the subject or objectively measured. Visual fatigue is usually considered an effect that declines more slowly after removal of the uncomfortable stimulus.~~

visual saliency: The ~~state or quality by which interested~~ regions on an image or video that stand out relative to ~~the other~~ areas. ~~regions~~

wavelet transform: In mathematics, ~~this is~~ a representation of a square-integral function by a certain orthonormal series generated by a wavelet.

3.2 Acronyms and abbreviations

2D	two <u>dimension</u> ~~dimensional~~
3D	three <u>dimension</u> ~~dimensional~~
ARD	adaptive rectangular design
ASD	adaptive square design
CIE	international commission on illumination
CVZ	comfortable viewing zone
<u>DeepVDP</u>	<u>deep visual discomfort predictor</u>
FPC	full paired comparison
GGD	generalized Gaussian distribution
HRC	hypothetical reference circuit
HVS	human visual system
MICSQ	multimodal interactive continuous scoring of quality
ORD	optimized rectangular design
OSD	optimized square design
PLCC	Pearson linear correlation coefficient
PMF	probability mass function
QoE	quality of experience
SRC	source video contents

SROCC	Spearman's rank correlation coefficient
SSCQE	single stimulus continuous quality evaluation
SVR	support vector regression

4. Ergonomic requirements and recommendations

4.1 General

When viewing a 3D image or ~~Unlike in two-dimensional (2D)~~ video, the ocular adjustment to 3D depth can induce neurological symptoms, such as visual discomfort and headache, and 3D distortions can ~~that~~ cause perceived quality degradation. To analyze the cause and estimate the degree of ~~Understanding~~ these problems, human ~~involves several intricate~~ visual factor-based analysis shall ~~factors that can only~~ be conducted regarding perception processing along with consideration of content characteristics. Additionally, this analysis shall be aligned with probed by ~~investigating the reliable spatial and temporal features in 3D contents and by using a~~ reliable subjective scores that are obtained using a proper subjective assessment procedure to secure reliability of the analysis result ~~testing methodology~~.

4.2 Visual saliency prediction

When viewing a 3D image and video, some scenes have only a few regions that cause visual discomfort and low QoE states. In this case ~~these cases~~, the viewer tends to pay more attention to this region, and the rest of the image is projected onto the retina with a low density of photoreceptors. Therefore, to develop a reliable human factor model ~~models~~ and ~~a~~ quality assessment metric, a concrete visual saliency prediction algorithm shall be developed.

4.3 Visual contents analysis

To analyze and predict the degree of the QoE or visual comfort when viewing a 3D content, it is necessary to understand the contents in terms of spatial and temporal characteristics that are based on existing psychophysical and statistical models of 3D visual perception.

4.4 Subjective assessment

~~Mostly, the~~ ~~Most~~ subjective assessment is inherited from what has been traditionally done for 2D subjective assessment as defined by ITU-T P.910, ITU-R BT.500-13, and ITU-R BT.2021.¹² However, it is ~~doubtable~~ ~~doubtful~~ whether ~~their~~ ~~these~~ results are reliable enough to be used as ~~reference~~ ~~references~~ because the viewing environment is quite different from 2D due to ~~the~~-intensive immersion of a user wearing the glasses in a ~~the~~-dark ~~lighting~~. Hence, to perform the subjective 3D image and video assessments, a ~~proper~~ ~~novel~~ interface shall be designed ~~while covering~~ ~~that covers~~ the characteristics of ~~the~~-human perception, display mechanism, ~~and~~ viewing environment, ~~and so on~~.

5. Visual saliency prediction

5.1 General

~~Definition and use of improved models of 3D perception is needed to~~ ~~An important ingredient in~~ further ~~improve~~ ~~improving~~ 3D video processing ~~techniques~~. ~~technologies is the effort to incorporate better models of 3D perception~~. Among these ~~models~~, saliency detection, or the automated discovery of points of high visual interest, conspicuity, or task relevance, is a challenging problem. This clause describes visual saliency prediction method by considering human visual system (HVS) characteristics.

5.2 Human visual system

To capture human factors or predict the visual discomfort of 3D contents, the ~~foveation~~ ~~characteristic~~ ~~characteristics~~ of the HVS ~~such as a retina and fovea~~ shall be considered ~~to take non-uniform photoreceptor density of retina into account~~.

¹² [Information on references can be found in Clause 2.](#)

The fovea is responsible for sharp central vision, which is needed in human beings for reading, watching television or movies, driving, and any activity where ~~for which~~ visual detail is of primary importance. As shown in Figure 1, the photoreceptors have a ~~photo-receptors possess~~ non-uniform spatial distribution with the highest density at the fovea, and the density decreasing ~~decreases~~ dramatically with distance from the fovea. Figure 1 describes ~~Here we describe how~~ the region with the highest saliency (obtained as described above) that falls on the fovea and, hence, has the highest sensitivity/resolution.

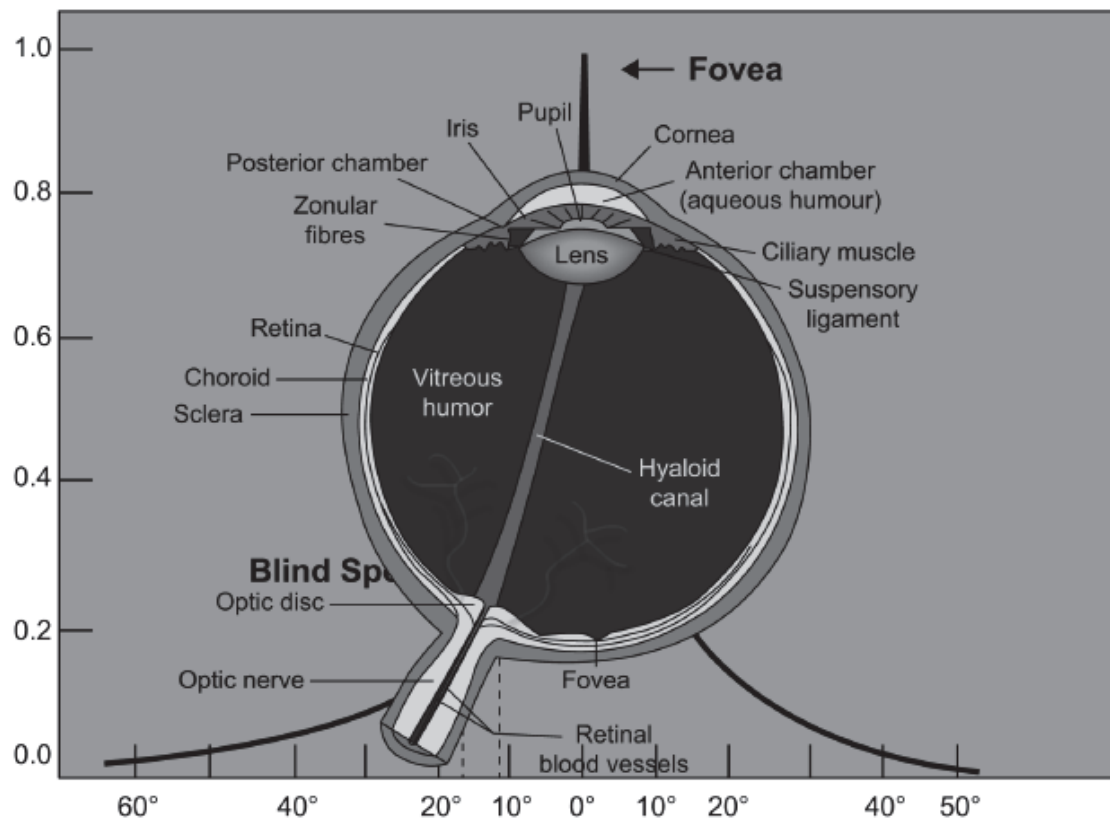


Figure 1_—Eye structure as a function of eccentricity

The foveation model used in this standard shall be represented as shown in Equation (1).

$$f\{V,(x,y)\} = \min \left[\frac{e^{\ln\left(\frac{1}{CT_0}\right)}}{a \left\{ e + \arctan\left(\frac{d}{VW}\right) \right\}}, \frac{\pi VW}{360} \right] \quad (1)$$