



# IEEE Standard for the Deep Learning-Based Assessment of Visual Experience Based on Human Factors

IEEE Computer Society

Developed by the  
Standards Activities Board

IEEE Std 3333.1.3™-2022

# IEEE Standard for the Deep Learning-Based Assessment of Visual Experience Based on Human Factors

Developed by the

**Standards Activities Board**  
of the  
**IEEE Computer Society**

Approved 9 February 2022

**IEEE SA Standards Board**

**Abstract:** Measuring quality of experience (QoE) aims to explore the factors that contribute to a user's perceptual experience including human, system, and context factors. Since QoE stems from human interaction with various devices, the estimation should be started by investigating the mechanism of human visual perception. Therefore, measuring QoE is still a challenging task. In this standard, QoE assessment is categorized into two subcategories, which are perceptual quality and virtual reality (VR) cybersickness. In addition, deep learning models considering human factors for various QoE assessments are covered, along with a reliable subjective test methodology and a database construction procedure.

**Keywords:** AR, augmented reality, cybersickness, deep learning, human factor, human visual system, HVS, IEEE 3333.1.3™, QoE, quality of experience, saliency detection, subjective assessment, virtual reality, visual experience, VR

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## Introduction

This introduction is not part of IEEE Std 3333.1.3-2022, IEEE Standard for the Deep Learning-Based Assessment of Visual Experience Based on Human Factors.

This standard is specifically written to high-end VR and AR service purveyors, 3D display and HMD makers, and the 3D digital cinema and gaming industry.

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# IEEE Standard for the Deep Learning-Based Assessment of Visual Experience Based on Human Factors

## 1. Overview

### 1.1 Scope

This standard defines deep learning-based metrics of content analysis and quality of experience (QoE) assessment for visual contents, which is an extension of the standard for the QoE and visual-comfort assessments of three-dimensional (3D) contents based on psychophysical studies (IEEE Std 3333.1.1™) and the standard for the perceptual quality assessment of 3D and ultra-high definition (UHD) contents (IEEE Std 3333.1.2™). The scope covers the following:

- Deep learning models for QoE assessment (multilayer perceptrons, convolutional neural networks, deep generative models)
- Deep metrics of visual experience from high definition (HD), UHD, 3D, high dynamic range (HDR), virtual reality (VR) and mixed reality (MR) contents
- Deep analysis of clinical (electroencephalogram (EEG), electrocardiogram (ECG), electrooculography (EOG), and so on) and psychophysical [subjective test and simulator sickness questionnaire (SSQ)] data for QoE assessment
- Deep personalized preference assessment of visual contents
- Building image and video databases for performance benchmarking purpose if necessary

### 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*).<sup>1, 2</sup>

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<sup>1</sup>The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

<sup>2</sup>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.

Recommendation ITU-T P.910, Subjective video quality assessment methods for multimedia applications.<sup>3</sup>

## 3. Definitions, acronyms, and abbreviations

### 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.<sup>4</sup>

**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.

**accommodation-vergence conflict:** Accommodation (eyes focusing on an object) and convergence (eyes pointing toward the object) are normally linked. Accommodation-vergence conflict is a conflict between accommodation (eyes focusing on the screen) and the convergence (eyes converging to a point in front of or behind the screen). Current 3D display technologies may induce accommodation-vergence conflict.

**cybersickness:** A form of motion sickness that occurs as a result of exposure to immersive environments.

**cyclopean image:** The image that is fused and perceived by the human visual system.

**disparity:** The difference in image location of an object seen by the left and right eyes, resulting from the eyes' horizontal separation (parallax). Disparity map implies the difference by number of pixels.

**field of view:** The swath width and all areas covered when the instrument is scanned.

**ground truth:** The actual nature of the problem that is the target of a machine learning model, reflected by the relevant datasets associated with the use case in question.

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<sup>3</sup>ITU publications are available from the International Telecommunications Union (<http://www.itu.int/>).

<sup>4</sup>IEEE 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.

**head mounted display:** A display worn on the body that fits over a user's head, which has small display optics in front of the eyes and is usually equipped with additional sensors to track the viewer's head motions such as coordinate positions, pitch, roll, and yaw. In some instances, the position of the user's gaze is also captured.

**immersion:** A psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences.

**presence:** The subjective experience of being in one place or environment, when one is physically situated in another place or environment.

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

**natural scene statistics:** It is concerned with the statistical regularities related to natural scenes.

**naturalness:** The perception of the stereoscopic image as being a truthful representation of reality (i.e., perceptual realism). The stereoscopic image may present different types of distortion that make it less natural. For example, stereoscopic objects are sometimes perceived as unnaturally large or small (puppet theatre effect) or they appear unnaturally thin (cardboard effect).

**photoreceptor:** A specialized type of cell found in the retina that is capable of visual phototransduction. The great biological importance of photoreceptors is that they convert light (visible electromagnetic radiation) into signals that can stimulate biological processes.

**presence:** The subjective experience of being in one place or environment, when one is physically situated in another place or environment.

**quality assessment:** Evaluation of quality of the service or product to determine the performance in relation to set standards.

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

**retina:** The sensitive layer of tissue at the back of the eye where sensory images are received.

**saliency:** Interested regions on image or video that is the state or quality by which it stands out relative to other areas.

**sharpness:** This is defined by the boundaries between zones of different tones or colors.

**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.

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

**viewing distance:** Distance between the viewer and display.

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

**visual experience:** The overall quality of experience of the visual stimuli in terms of immersion.

**visual fatigue:** Visual fatigue is generally caused by the repetition of excessive visual effort and can build up as these efforts are repeated. It disappears after sufficient rest. Visual fatigue is a medical state that may be objectively diagnosed by the presence of objective indications (medical signs) and subjective indications (medical symptoms). Visual fatigue can only be diagnosed by a medical doctor.

### 3.2 Acronyms and abbreviations

|       |                                                  |
|-------|--------------------------------------------------|
| 2D    | two-dimensional                                  |
| 3D    | three-dimensional                                |
| ACR   | absolute category rating                         |
| AGGD  | asymmetric generalized Gaussian distribution     |
| ADAM  | adaptive moment                                  |
| AI    | artificial intelligence                          |
| AR    | augmented reality                                |
| CNN   | convolutional neural network                     |
| CSF   | contrast sensitivity function                    |
| DFT   | discrete Fourier transform                       |
| DMOS  | differential mean opinion score                  |
| DoF   | degree of freedom                                |
| DSCQS | double stimulus using a continuous quality scale |
| DSCS  | double stimulus comparison scale                 |
| DSIS  | double stimulus impairment scale                 |
| EM    | eye movement                                     |
| ERP   | equirectangular projection                       |
| FC    | fully connected                                  |
| FoV   | field of view                                    |
| FR    | full reference                                   |
| GAN   | generative adversarial network                   |
| GGD   | generalized Gaussian distribution                |
| GPU   | graphic processing unit                          |
| HD    | high definition                                  |
| HM    | head movement                                    |

|       |                                               |
|-------|-----------------------------------------------|
| HMD   | head-mounted display                          |
| HRTF  | head-related transfer function                |
| HVS   | human visual system                           |
| IQA   | image quality assessment                      |
| LCC   | linear correlation coefficient                |
| LSTM  | long short-term memory                        |
| ML    | multilevel                                    |
| MLP   | multi-layer perceptron                        |
| MOS   | mean opinion score                            |
| MR    | mixed reality                                 |
| MSCN  | mean subtracted contrast normalization        |
| MSE   | mean-squared error                            |
| NN    | neural network                                |
| NR    | no reference                                  |
| PLCC  | Pearson's linear correlation coefficient      |
| PSNR  | peak signal-to-noise ratio                    |
| QoE   | quality of experience                         |
| QP    | quantization parameter                        |
| RGB   | red, green, and blue channels                 |
| RMSE  | root mean squared error                       |
| RR    | reduced reference                             |
| SROCC | Spearman's rank correlation coefficient       |
| SSCQE | single stimulus continuous quality evaluation |
| SSIM  | structural similarity                         |
| SSQ   | simulator sickness questionnaire              |
| SVD   | singular value decomposition                  |
| SVM   | support vector machine                        |
| SVR   | support vector regression                     |
| S3D   | stereoscopic three-dimensional                |
| TV    | television                                    |
| UHD   | ultra-high definition                         |
| VQA   | video quality assessment                      |

|    |                  |
|----|------------------|
| VR | virtual reality  |
| XR | extended reality |

## 4. Synopsis of the standard

### 4.1 General

Measuring quality of experience (QoE) aims to explore the factors that contribute to a user's perceptual experience including human, system, and context factors. Since QoE stems from human interaction with various devices, the estimation should be started by investigating the mechanism of human visual perception. Therefore, measuring QoE is still a challenging task. In this standard, QoE assessment is categorized into two subcategories—perceptual quality and virtual reality (VR) cybersickness. In addition, deep learning models considering human factors for various QoE assessments are covered, along with a reliable subjective test methodology and a database construction procedure.

### 4.2 Quality of experience assessment for 2D, 3D, and VR/AR contents

This standard covers various types of visual contents such as two-dimensional (2D), three-dimensional (3D), VR, and augmented reality (AR). Based on these multidimensional experiences, various QoE elements such as visual quality, cybersickness, and sense of presence are described. For an objective assessment of these elements, various perceptual features shall be extracted regarding each content characteristic and human visual system (HVS) model depending on the prior knowledge of each different media and device type. The features are then incorporated together to obtain the objectively predicted scores by the pooling or regression process. This process can be executed in various forms, from closed-form expression to data-driven methods such as support vector regression (SVR) and deep learning.

### 4.3 A database of immersive contents

To construct an immersive content database for QoE assessment, a realistic experimental environment should be considered to obtain an accurate subjective QoE score. To do this, it is necessary to create/develop a proper subjective test methodology and reliable visual content according to each QoE element. Besides, the immersive content database should include the characteristics of human perception, media formats, display mechanisms, and interactions in the content organization and visualization process. In this standard, various subjective test methodology of subjective scales of the QoE elements are introduced, such as cybersickness and sense of presence.

## 5. Quality assessment of visual contents

### 5.1 General

The visualization of 3D contents is more complex than those of other media types. These contents can be presented to users through various devices such as 3D displays and head-mounted displays (HMDs). This enables users to interact with spaces and objects. Thus, the quality assessment of these contents is required to improve users' QoE. However, conventional 2D video/image quality assessment algorithms are not applicable to panoramic 360 contents due to the spherical characteristics and the existence of sphere-to-plane