

# Stereoscopic Image Perception Quality Factors

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**Abstract**—Stereoscopic films and interactive presentations are extensively popularized whereas their perceived quality still dissatisfies viewers. The reasons are shared between hardware inconsistencies and stereo image producers unawareness concerning factors influencing depth perception quality. This paper reviews aspects influencing 3D image perception visual comfort, presents visual comfort estimation methods and suggests how to measure image perception quality.

**Keywords**—stereoscopic image; image quality factors; perception convenience;

## I. INTRODUCTION

Human vision system is the most valuable and reliable source of information concerning surrounding world coming indirectly to observers' brain (about 80% of all human body sensors stimuli [1]). Objects' colors, shapes, surfaces features, interrelations and their movements are registered by human eyes and consequently perceived and interpreted as a spatial visual experiences. Three dimensional scene experience can be available also due to sophisticated techniques providing human eyes with stereo pair of images recorded by real or virtual stereo cameras. Unfortunately current techniques, even professional ones, do not respect all the depth perception factors characterizing real spatial image. Furthermore probable stereo cameras' inconsistencies and film production errors further drastically may decrease the visual comfort.

Provided paper aggregates all main factors influencing stereoscopic image perception quality and puts attention to most common errors and artifacts of the stereoscopic material production process. It suggests how stereoscopic image quality, from the human perception point of view, can be measured and describes experimental testing environment that might be used for testing professional stereo material in relation and users perceived impressions.

## II. FACTORS AFFECTING STEREOSCOPIC IMAGE PERCEPTION

Among several factors affecting stereo image perception quality three main groups can be distinguished according to the origin of artifacts. First group is connected with hardware and technology inherent parameters, second group encompasses cameras settings that should be possibly correlated to the human visual system behavior and third concerns parameters of the content presented in the image and its motion (fig. 1).

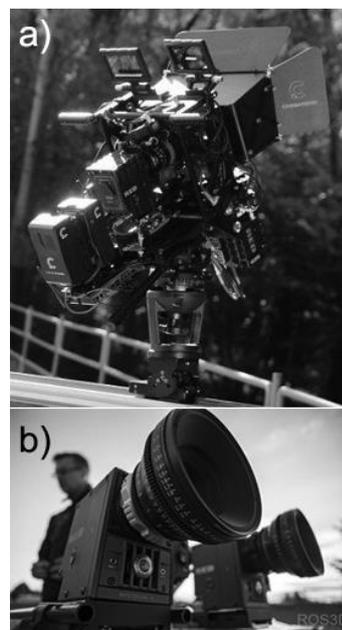


Fig. 1 CinemaVision stereoscopic rigs: a) perpendicular; b) parallel;

The first presented group of factors is more hardware and technology dependent and it just faintly depends on camera operators. Discrepancies between left and right eye dedicated images perceived as binocular asymmetry in geometry, luminance, color or focus, cause that each eye perceives image aberrations not corresponding to human vision system and result in visual discomfort (fig. 2).



Fig. 2 Discrepancies between left and right eye images; (upper stereo pair from Resident Evil) asymmetry in luminance; (bottom stereo pair fragment from Galapagos: The Enchanted Voyage) asymmetry in sharpness;

Technological problems of left/right images separation (crosstalk) also affect depth perception as two eye's dedicated images are registered unexpectedly as ghost objects. Additionally viewing conditions such as limited screen size or inappropriate distance to the screen with its borders falling into field of view may also decrease visual comfort as presented depth is unintentionally trimmed in an unnatural way. The frame effect occurs when objects positioned in front of the screen approach the screen frame. Stereoscopic display screens characteristics are also a source of very well-known and studied visual fatigue factor caused by inconsistency between accommodation and convergence (fig. 3). Inconsistency between accommodation and convergence occurs when the focus point (accommodation) is not fixed on the screen plane, nondependent of the convergence point which is derived from the disparity of the signals. Uncoupling of convergence and accommodation required by 3D displays frequently reduces one's ability to fuse the binocular stimulus and causes discomfort and fatigue for the viewer. This discrepancy between accommodation and convergence demand may be highly stressful for the visual system.

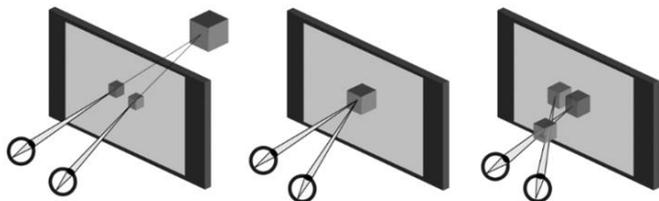


Fig. 3 Accommodation and convergence conflict. Convergence follows perceived object depth whereas accommodation remains at the screen surface.

Second group of factors encompasses discordance between human visual system parameters and simulating them corresponding cameras' settings (i.e.: horizontal (base) distance, convergence, depth of field) adjusted by the cameras' operator. This group comprises valid and operators' dependent key aspects and will be further thoroughly studied.

The first and probably the most obvious factor influencing perception is cameras horizontal separation (cameras' base distance) that should reflect viewers' inter ocular distance (IOD). As among human races and people age IOD differs there is no chance to theoretically satisfy all viewers with one universal camera distance. On the other hand it is usually assumed that average population inter ocular distance is 65 mm and most researchers treat it as reference value [2]. Some interactive stereoscopic applications let the user adapt IOD to personalize the view.

Subsequent factor that should be taken into consideration is cameras convergence reflecting human visual system point of interest eyes fixation. People exploring their field of view fix their gaze on certain points (objects) in space (horopter). Eye bulbs are naturally rotated until the object are positioned on the main visual track of the eye. As a result physiological parallax of the observed objects (scene corresponding points retina displacement – fig. 4) is registered and transformed into the perceived scene depth. Eyes convergence is accompanied

by performed automatically accommodation which technically is simulated by camera focus.

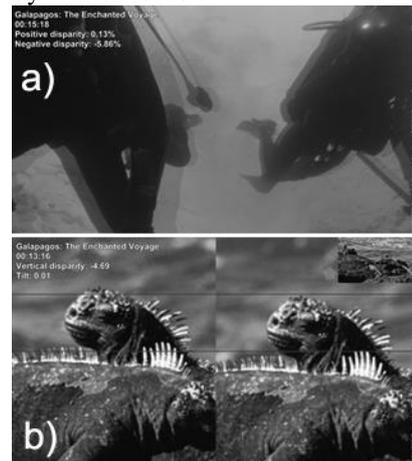


Fig. 4. a) horizontal parallax/disparity (base dependent); b) vertical disparity

Unfortunately during natural scene observation human gaze very dynamically changes its fixation point (scanning path, saccades, etc.) what is almost unavailable for regular cameras recording system which is usually fixed or slightly adjustable for the whole shot or the scene. Cameras' operators have to guess or even suggest what the viewer might be interested in. It may not only not suite all the viewers but several production or post-production errors (convergence-focus inconsistency, vertical disparity) may affect the final experience as well. Wide range of camera parameters decorrelation frequently results in not physically valid stereoscopic material.

It must be also mentioned that human beings limited depth ability [3] inclines operators to experiment with cameras base distance and their convergence as to enlarge presented scene depth and make the production more immersive. Unconstrained and neither physically nor technically justified parameters (i.e. size of the display screen) become a source of many destructive and uncomfortable settings forcing cross-eye or divergent squint.

The third group of factors affecting stereoscopic scene perception is connected with presented content. Appropriate objects appearance, their contrast with background and relative movement should reflect real environment situations. Especially artificially rendered objects and their programmed animations are susceptible to inconsistent with reality. These aspects affecting visual comfort require separate investigation and are not discussed in this paper.

### III. VISUAL COMFORT TESTING METHODS

Visual comfort is closely connected with visual fatigue (tiredness, headaches, and soreness of the eyes). However visual comfort can be considered in relation to the objective indicators of visual fatigue [4, 5] and subjective signs accompanying visual discomfort. Subjective indicators measurement methods may be described by the human perceptual opinion (Quality of Experience). International Telecommunication Union [5] has recommended methodology for the subjective assessment of the quality of television

pictures. They proposed two classes of subjective assessments: quality and impairment assessments. They also described specific environmental conditions, for this type of indicators. Subjective measurement methods of visual comfort include subjective self-assessments such as assessment scales and questionnaires. Simultaneously various objective evaluation methods of fatigue have been proposed and different devices, like brain activity measures (EEG, fMRI) as well as optometric and galvanic skin response (GSR) instruments, were widely used.

#### A. Subjective Measurement Methods

Binocular asymmetry may be measured both by subjective and by the objective methods as well. There are three categories of the binocular asymmetries (color, geometry, luminance). First mismatch is known as the binocular color fusion limit. Subjective experiments to measure the color fusion limit use single stimulus assessment [6,7]. Zhao et al. [8] proposed a difference model based on two psychophysical experiments by modeling and incorporating the binocular combination of injected noises, luminance masking and contrast masking in binocular viewing. This model measured the perceptible distortion threshold of stereoscopic images for binocular vision. Geometry mismatches are based on asymmetrical optical geometry (e.g., image shift, rotation, magnification) [9,10]. Geometry mismatches when the head is rolled relative to the display was made by behavioral experiments in which authors simulated head roll by rotating the stereo display [11]. Binocular asymmetry of brightness combination [12] occurs when the input brightness is asymmetric in both eyes. This phenomenon is when a bright light to one eye may appear less bright when a dim light is shown to the other eye. 2D image quality metric (e.g. PSNR) cannot be directly applied to test these asymmetry. This statement can be verified by the low correlation between the computed objective measures and the subjectively measured mean opinion scores. Experimental results of researchers from National Taiwan University [12] show that significant consistency could be reached between the measured mean opinion scores and the Binocular Frequency Integration-based metrics.

Another source of viewing discomfort associated with subjective visual comfort assessment method is cross talk. In a perfect stereoscopic display, the one eye image should be seen by the dedicated eye only and should be completely invisible to the other eye. Total separation of eye images is often impossible. Cross talk produces ghosting effects and is a potential cause of headaches [13]. Pastor et al. established visibility thresholds for cross talk using a system with perfect left/right image separation (a high resolution mirror stereoscope; the experimental conditions were generated with image processing techniques). Subjective tests reveal that visibility of cross talk increases with contrast and increasing binocular parallax (depth) of the stereoscopic image. In this situation reason of discomfort viewing is that range of DOF, concurs with the range of fusion.

Kim et al. [14] investigated the effect of convergence–accommodation conflict and parallax difference on binocular

fusion for random dot stereograms. They measured the time required for fusion under various conditions that include foreground parallax, background parallax, focal distance, aperture size, and corrugation frequency. They found the relationship between fusion time and visual fatigue by conducting a subjective evaluation of stereoscopic images.

Visual comfort received local low evaluation scores for scenes with high degrees of screen disparity and high amounts of motion [15]. Experiments confirmed that discrete changes of motion in the depth direction cause significant decrease of visual comfort [16]. Experiments have shown that visual fatigue was not a serious problem when still stereoscopic images, which were only perceived by convergence eye movement, were displayed within the corresponding range of the depth of focus. It was also found that visual fatigue occurred when the stereoscopic images involved the depth motion component were displayed, even if they were shown within the range of the depth of field. Based on the subjective measurement methods, it was tested that binocular disparity induced visual discomfort [17]. Authors used two subsets of comfort videos and discomfort videos for the subjective assessment of visual comfort. After collecting all subjective ratings, mean opinion score (MOS) of visual comfort was calculated for each video stimulus. Subjective evaluation can be used to quantify the level of visual discomfort and fatigue. Subjective measurement methods evaluation were used to estimate the level of discomfort. as it is a subjective phenomenon by nature [18,19,20]. These measures are more encumbered with errors affected by individual variation of human visual fatigue.

#### B. Objective Measurement Methods

Objective measurement methods can obtain information about the level of visual and cognitive fatigue with optometric and brain measurement devices [18].

Optometric measurements were used to verify the physiological parameters of human vision, such as changes in the accommodation-convergence function, pupil size, and blinking rate [19, 20, 21, 22].

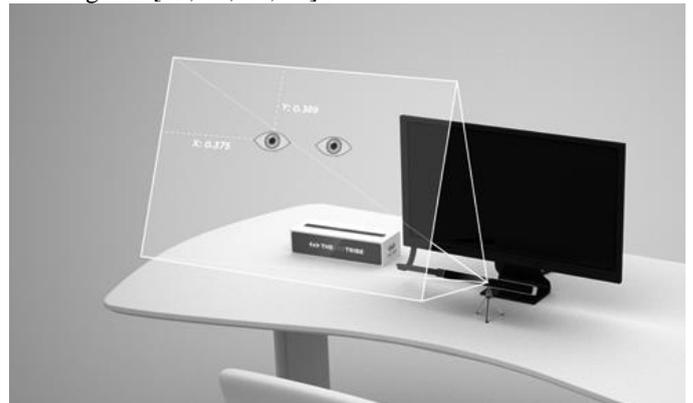


Fig. 5 Optometric instrument (The Eyetrack Tracking System) to perform measurement of stereoscopic movies

Optometric instruments are available to perform the objective measurements of changes in the dynamics of the eyes like pupil diameter, gaze tracking or blinking rate. The

eyes are illuminated with an infrared light pattern and when reflected it is registered and analyzed. In this manner, the changes in the physiological parameters of the eyes in response to a specific stimulus can be dynamically recorded (fig. 5).

Accommodation-convergence conflict [23] was tested with optometric instruments [24, 22]. Jansen et al. used 2D and 3D natural and noise images to investigate the effect of additional binocular information on basic eye movement. They found a correlation between disparity and the selection of fixation points and change in basic eye movement properties when disparity information was present. Autorefractor [25, 26] was used to allow objective, continuous, open-field measurement of accommodation and pupil size for the investigation of the visual response to real-world environments and changes in the optical components of the eye. Brain activity measures (EEG, fMRI) may estimate cognitive fatigue underlying 3D visual fatigue. Functional magnetic resonance imaging (fMRI) was used for the objective measurement to assess the human brain regions involved in the processing of the stereoscopic stimuli with excessive disparities [17]. The subjective measurement results, were used to find subsets of comfort and discomfort videos. Then, a fMRI experiment was conducted with the subsets of comfort and discomfort videos in order to identify which brain regions were activated while viewing the discomfort videos in a stereoscopic display. 3D visual fatigue was also measured by background EEG and ERP signals [27]. Power of beta frequencies increased as watching duration increased and it was much stronger in 3D rather than in 2D condition. More importantly, P700 delayed as watching duration increased as well as in 3D rather than in 2D condition. Similar pattern of results was obtained in the measured subjective 3D visual fatigue.

Visual comfort assessment is playing an important role for stereoscopic safety issue. Ye Bi and Jun Zhou [30] proposed visual comfort assessment metric that utilizes interest salient motion regions where human subjects focus on. To achieve better performance, this approach combines salient cues, motion cues with depth cues in order to extract salient motion regions in consideration of depth context. The experimental results have demonstrated that proposed visual comfort assessment improves the correlation with the subjective assessment. The "Video Quality" scale is a very complex problem and the Quality of Experience (QoE) of 3D video is a multidimensional concept and therefore more than one scale is in many cases needed for subjective assessment of the QoE of 3D video [31].

Measurement of visual discomfort can be performed using the tracking physiological response of the observer. Such reactions may include eye pressure, blink frequency or eye movement.

#### IV. MEASURING VISUAL FATIGUE AND DISCOMFORT OF 3D IMAGES PERCEPTION

The quality metric to measure impaired stereoscopic video is still a popular research area [32, 33, 34]. A visual comfort metric for stereoscopic 3d video quality is still in its early

stage. 2D image quality metrics are useless for 3D images [36, 37, 38]. For measuring the perceived quality of stereoscopic images, several metrics have been proposed by integrating 3D perceptual properties. Da Silva et al. [32] made a statistical analysis of two subjective experiments conducted to analyze the quality assessment techniques for compressed stereoscopic video. This metric and the subjective results database are publicly available, for the 3D media delivery systems. Xing et al. [38] proposed quality evaluation of crosstalk perception on polarized stereoscopic display. Kulyk et al. [31] proposed quality assessment with multi-scale subjective method based on state-of-the-art physiological and psychological understanding of the human visual system. Juszka et al. [39] proposed an objective, bit stream quality metric for stereoscopic high definition video affected by compression and packet loss in a network. Ryu et al. [40] proposed stereoscopic image quality metric based on binocular perception model for stereoscopic images model considering asymmetric property of a stereoscopic image pair. Experiments for publicly available databases show that the proposed metric provides consistent correlations with subjective quality scores. Subjective evaluations of 3D image were conducted to investigate the influences of 3D factors to a perceived quality of 3D image. In order to measure an objective quality of a stereoscopic image, several full-reference quality metrics have been proposed using the fusion of 2D quality metrics and depth distortion [41, 42]. Measured depth acuity is slightly higher after 3D viewing than after 2D viewing [43]. Visual fatigue is related to many different aspects of the human visual system. Visual discomfort is more subjective and almost all studies evaluating discomfort by questionnaires provided significant indicators for measuring visual fatigue. These questionnaires were based on potential symptoms or source of visual discomfort and ask the viewers to identify more precisely the source of their discomfort [20, 24]. Researchers have proposed many approaches which usually use global statistics for stereoscopic 3D video visual comfort assessment [44, 45, 46]. They use a continuous evaluation of visual comfort similar to the Single Stimulus Continuous Quality Evaluation (SSCQE) method [5]. They have found differences in terms of individual's tolerance of visual discomfort and fatigue. These differences are linked to some normal differences in visual processes or to some form of stereo-anomaly. This generate problems for flexible and correct metrics. For example accommodation ability and maximum pupil diameter decline with age. The maximum pupil diameter reduces from 8 mm over 6 mm to approx. 2...3 mm [47]. Individual differences are the main problem for the definition of general and easily applicable indicators of visual fatigue and visual discomfort. Reichelt et al. [47] proposed measuring image quality and visual comfort with the depth cues of the human visual perception. Their analysis were based especially on near-range depth cues and compared visual performance and depth-range capabilities of stereoscopic and holographic displays. They have proposed a "safety depth zone" for stereo displays, which had to compromise considerably on utilizable depth. Lambooj et al

[4, 15] have defined visual fatigue as physiological strain or stress resulting from excessive exertion of the visual system. They applied visual fatigue for objectively measurable symptoms for a stereo comfort zone. They have appointed indicators, both objective and subjective, for measuring visual fatigue and visual discomfort associated with 3D displays. Jae Gon Kim et al. [48] have also researched on visual fatigue and visual discomfort with displays. They proposed Simplified Relative Visual Fatigue model to evaluate the degree of the visual fatigue in a stereoscopy. They considered “accommodation and convergence” factors that can be calculated by disparities in a stereoscopy. Song-Pei et al. [49] proposed metric of visual comfort for stereoscopic motion. Based on measurements of the visual discomfort and caused by motion in stereoscopic content, a metric was proposed to evaluate the level of comfort associated to viewing short stereoscopic videos. This is important that visual comfort metrics had the correlations with subjective judgment. Visual comfort metrics that quantify the level of visual discomforts are very important for sustainable development of stereoscopic videos in future.

#### V. WORK STAND FOR PERCEPTION BASED 3D IMAGE VISUAL FATIGUE EVALUATION

Authors have designed the test bench allowing to examine the eye reaction of the tested person (fig. 6).



Fig.6 Original project of optometric instrument (CinemaVision Movie Diagnostics) to perform measurement of stereoscopic movies.

It is composed of The Eyetribe sensor which is responsible for the user gaze point tracking and wearable part – polarized glasses with micro video camera mounted on – responsible for detection blinking rate and pupil diameter monitoring. Though eye tracker vendors claim that the device is capable to retrieve pupil diameter and blink rate the obtained results, though filtered [50], did not reflect reliably eyesight biomechanics. That is why the decision regarding additional wearable camera was made. Additionally mouse controller is used to let the

tested person mark any remarkable moments which should be next explained within a questionnaire. These three biomechanics factors were identified as functional indicators influencing observers’ visual fatigue/comfort in 3D films watching context. Supplementary introspection was introduced to collect descent explanation of experienced moments.

Experimental tests have revealed that elaborated work stand reliably reflects gaze point, but retrieving gaze pointed content characteristics still requires manual image analysis. Therefore the work stand will be further developed in order to automate stereoscopic image analysis as to find out possible correlations between users’ biomechanics accompanied with biophysical reactions and corresponding image quality characteristics. The goal of forthcoming researches is to elaborate non-reference automatic 3D image quality metric which has a human visual system background. Then it can be applied for boosting and optimizing highly expensive 3D films making process.

#### VI. CONCLUSION

One of the goals of conducted studies was to investigate the aspects influencing 3D image perception visual comfort and suggest how to verify image perception quality as well as provide measures correlated with dedicated eye tracking experiments. Future research will focus on measuring a quality of stereoscopic images and comparing results with other existing metrics. We plan to extend our research to establish guidelines for stereoscopic videos tests to determine objective quality assessment metrics for 3D. The researches has already originated with the advanced visual comfort testing work stand elaboration which is planned to be further developed.

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