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Eye and EEG activity markers for visual comfort level of images

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ABSTRACT

Depth perception by binocular cues is based on the matching of image features from one retina with corresponding elements from the second retina. However, high disparities are related to the higher visual discomfort levels and may cause the eye fatigue during extended stereoscopic perception time. The goal of the investigation was to find a set of measurable features for stereoscopic image visual comfort level prediction. The investigation involved gaze, pupillometric and EEG data from 28 subjects who evaluated visual comfort level of 120 stereoscopic images. Six different time frame windows were used to analyze four measured features: the number of focus points; the dynamics of pupil size; disparity level at the focus points; the activity of EEG bands at the frontal lobe. A significant difference was found in all investigated stereoscopic image groups. 2-s and 5-s pre-DPI window showed best results for the selected feature sets. The higher disparity at the focus points, lower number of focus points are related to the lower levels of visual comfort. However, features such as the number of focus points, the pupil size and the disparity level for the images with lowest visual comfort scores showed similar results to the images scored as ''comfortable'' or ''very comfortable''.

1. Introduction

The presented investigation focuses on the eye fatigue problem. The problem arises during sustained visual perception of stereoscopic content [1]. The importance of this problem is supported by the increased attention to the head-mounted displays, such as VR glasses and immersive visual content (e.g., 360-degree video records) [2,3]. A stereoscopy effect is achieved by presenting an individual view for each eye. The disparity between two views gives a possibility to support better depth perception. The disparity between image objects helps to distinguish similar objects situated at different distances from the viewer. However, high disparities are related to the higher visual discomfort levels and may cause the eye fatigue during extended stereoscopic perception time [4–7].

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The variety of display technologies and visualization techniques that we currently use in consumer electronic devices produces images with a different level of visual comfort. Main factors which influence visual comfort (discomfort) are: stereoscopic parallax [5], level of vergence-accommodation conflict [8,9], crosstalk [10] and depth of field [11]. Several additional factors, such as motion [7], puppet theater and cardboard effects [12] can also be the cause of discomfort, though they are not always present in the stereoscopic content. Simulation of depth relies on different cues and visualization systems apply various techniques to enhance the depth perception: perspective, disparity, blur, shading, haze, and motion [4].

The assessment of visual discomfort can be performed in two ways: the subjective one and the objective one. During the subjective assessment, visual tests are presented to a group of viewers, which during the experiment (or after it) fills the questionnaire about their impressions on different stereo images or long-lasting video. The objective measurements require observing the body response during stereoscopic perception of differently rendered stereoscopic images. The most widely used tools to follow the body response in this research field is eye-tracking devices [13–16] and brain scanning devices [17–29]. However, other means to measure visual discomfort was also investigated, e.g., Lee et al. showed it is possible to measure visual discomfort using facial expressions [30].

Professional eye-trackers usually can track not only the point of gaze but also the dynamic changes of the pupil size. Lin et al. analyzed relations between parallax, a number of fixations, duration of fixations versus the distance to the 3D screen [13]. Iatsun et al. investigated intensity of eye movement, blinking and pupil size changes [14]. Bernhard et al. proposed a concept of gaze-controlled disparity adjustment [15]. Kim et al. investigated fixation behavior in stereoscopic images, and their proposed method showed positive results in evaluating visual discomfort of stereoscopic images [16].

The most popular way of performing brain signal scanning during the stereoscopic perception is EEG sensing device. There are some recent works, focused on measurement of brain activity in different areas of the brain to identify the most active ones [17–19]. Fischmeister et al. extended list of previous research work on non-natural images with an investigation of depth cues from natural stereoscopic images [20]. Fazlyyyakhmatov et al. analyzed the power of cortical activity during cognitive tasks [21]. Zou et al. investigated effects of visual fatigue during random dot stereogram based tasks using six ratios of EEG activities [22]. Various researchers use EEG based measurements to estimate different levels of visual fatigue using 2D and 3D displays [23,24]. In addition, few papers analyze visual discomfort measurement possibilities using fMRIs [25] and Event-Related Potentials (ERP) [26]. However, the analysis of ERP did not show a noticeable difference after watching 3D movies [27–29].

Our investigation aimed to identify a set of visual comfort-related features, that could be estimated using eye tracking device and consumer-grade EEG sensing device. Interesting research results on subjective evaluation of stereoscopic images, taken from IVY LAB 3D image database [31], were analyzed in few previous works [32,33]. In recent years, subjective evaluation was used as a reference for the development of objective assessment methods, e.g., human visual system-based, evaluating binocular disparity, blur, spatial frequency [34]. Jiang et al., in their work [35,36], introduced disparity features, such as magnitude, contrast, dispersion, skewness, and also combined oscillatory activities of the middle temporal area, for the assessment of visual discomfort. Performance of their methods was evaluated on NBU S3D-VCA [37] and IVY LAB 3D [31] databases.

In our investigation we have invited a group of volunteers to perform a set of individual tests on IVY LAB stereoscopic image dataset [31] for this purpose. We have selected this database for our investigation in order to be able to compare our subjective evaluations with those, collected during experiments made by others. Each participant was asked to indicate the moment of the visually comfortable depth perception and rate the image comfort level from 1 to 5 (5 is the visually most comfortable) during the experimental investigation, performed in our laboratory. Information about time for participants to reach stable depth perception (identify a stereoscopic stimulus) is important in situations when content is changed suddenly, and a different level of visual comfort is induced. Hoffman et al. showed that in addition to increased viewers fatigue and discomfort, distortions in 3D displays also increases the time required to identify a stereoscopic stimulus [9].

Four objectives were formulated to achieve the aim of the investigation. The first objective was to estimate the number of focus points on an image for a user before the Depth Perception Indication (DPI) occurs and if the number of focus points correlates with the visual comfort level. The second objective was to determine a relative pupil size during analysis of stereoscopic images of the investigated dataset and find how it correlates with the visual comfort level, assigned to the image. The third objective was to see the relationship between eye disparity at each focus point and image visual comfort level designated by the user. The fourth objective was to measure and analyze the EEG activity on the frontal lobe and investigate the activity tendencies with the changes of visual comfort levels. We expected that the number of focus points, the pupil size, the eye disparity and the activity of EEG would be affected by different visual comfort levels since natural mechanisms of binocular vision are violated with the usage of artificial stereoscopic cues.

2. Methods

The IVY LAB stereoscopic 3D image database [31] of 120 stereoscopic images was used for investigation. Level of the visual comfort of each image was rated by the subjects on a scale from 1 to 5 (extremely uncomfortable to very comfortable). This dataset contains stereoscopic images with urban, nature, indoor objects including humans and non-living entities. Image resolution is 1920×1080 pixels with the magnitude of crossed disparity ranging from 0.11 to 5.07 degrees.

A group of 28 subjects (25 males and three females) participated in our experiment as volunteers. Subjects received no rewards or compensations for their participation. Their age varied between 19 and 37 years old with an average of 22 (with Standard Deviation of 4). All volunteers were informed about procedure, goals, subjective assessment phase