Study on the Perception of Sharpness Mismatch in Stereoscopic Video

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***Abstract*—In this paper, we study an artifact of stereoscopic 3D (S3D) video called sharpness mismatch (SM), that occurs when one view is more blurred than the other. SM beyond a certain level can create visual discomfort, and consequently degrade the quality of experience. Therefore, it is important to measure the just noticeable sharpness mismatch (JNSM), i.e., the minimal level of SM that is perceived by the human visual system and creates discomfort. The knowledge of the JNSM can be used in the evaluation of the quality of S3D video, and more in general when processing S3D video, like in asymmetric compression. In this paper, we focus in particular on the detection of SM. For this goal, we organized a psychophysical experiment with 23 subjects and a crosstalk-free stereoscopic display in order to gather psychophysical data necessary for the development of a SM detection method. Based on the gathered experiment data, we propose a new SM detection method. The evaluation of this method shows that its performance is close but not better than that of the state-of-the-art methods. Therefore, our goal in the near future is to improve the proposed method.**

***Index Terms*—Sharpness mismatch, Binocular suppression, Interocular blur suppression, Stereoscopic 3D video, 3D quality assessment**

I. INTRODUCTION

S3D video consists of two videos captured from different viewpoints, that, when viewed separately by the two eyes, can create the illusion of depth perception. S3D video can have different issues, such as binocular rivalries and conflicts of depth cues. In this paper, we consider in particular the artifact called sharpness mismatch (SM). This artifact can be introduced in the video during the shooting with two cameras that have different focal lengths or aperture settings, or by asymmetric compression.

When a S3D video has a low level of SM, it can happen that the viewer doesn't perceive it, that is, she/he perceives the video as sharp as the sharpest of the two stereoscopic views. The mechanism of the human visual system behind this behaviour is called interocular blur suppression [1]. The focus of this paper is to analyze the limits of interocular blur suppression, i.e., to find the limits where the human brain is not able to suppress SM any longer. In other words, we study the just noticeable sharpness mismatch (JNSM): given a S3D image without SM, the JNSM is the minimal amount of blur applied to one of the two views, so that the viewer perceives a difference with respect to the original S3D image.

In the scientific literature, there are different publications about binocular suppression [1]–[5], which is a mechanism related to interocular blur suppression. Binocular suppression occurs when the stereoscopic views are of different quality (i.e. not only sharpness mismatch), and the higher quality view dominates the perceived quality. Binocular suppression was studied by Julesz [2] based on experiments with random dot stereograms. It was also investigated in studies related to monovision correction [3], [4], and asymmetric compression [1], [5]. For example, [5] recently introduced a new state-of-the-art asymmetric compression method. The JNSM was also studied in [1] with a psychophysical experiment using as visual stimuli wave gratings with vertical and horizontal orientations, and with different contrasts and spatial frequencies. It was observed that orientation, contrast, and spatial frequency don't have a large influence on the JNSM.

In this paper, we present a psychophysical experiment that extends the study in [1] by exploring how the JNSM is influenced by other two dimensions of the wave grating stimulus: the symmetric blur, i.e., blur equally applied to the two views, and the disparity. The main motivation of the experiment is to gather psychophysical data to develop a method for the detection of SM. Our aim is to develop a method based on more accurate and extensive psychophysical data about SM perception compared to other methods, in order to have a more accurate and reliable method. The evaluation shows that our method achieves good but not better results than the state-of-the-art. Thus, it requires further development in future work. In conclusion, we expect that the findings from our experiment will be beneficial for future studies not only in S3D quality evaluation, but also in asymmetric compression, and more in general in processing of S3D video.

The remainder of this paper is organized as follows. In Sec. II, the psychophysical experiment is presented. Then, we introduce the proposed method for sharpness mismatch detection in Sec. III, and we conclude the paper in Sec. IV.

II. PSYCHOPHYSICAL EXPERIMENT

The goal of the experiment is to measure the JNSM for the development of a new method for SM detection. In particular, we selected stimuli necessary to develop the core of our method, that is, a criterion for the evaluation of the perceived sharpness mismatch at the edges in a S3D image. In order to measure the JNSM in the experiment, two stimuli identical except for SM were shown at the same time. One stimulus was

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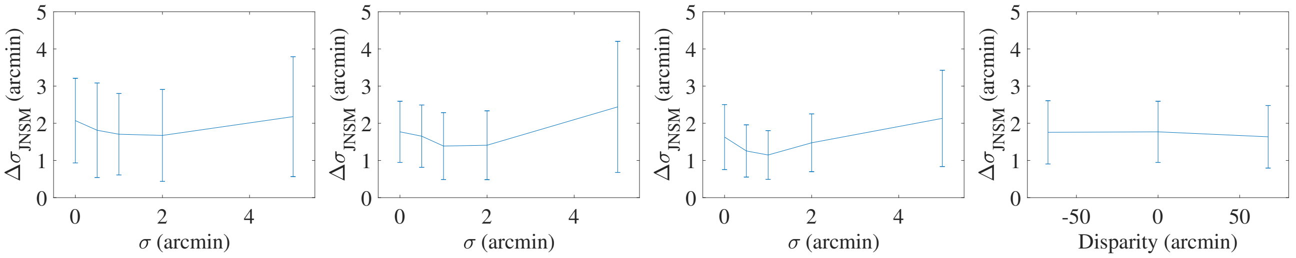

(a) Stimuli with Michelson contrast 0.20 and zero disparity.

(b) Stimuli with Michelson contrast 0.50 and zero disparity.

(c) Stimuli with Michelson contrast 0.98 and zero disparity.

(d) Stimuli with Michelson contrast 0.50 and $\sigma = 0$.

Fig. 1: Plots of the average $\Delta\sigma_{JNSM}$ with standard deviation of the subjects' $\Delta\sigma_{JNSM}$ illustrated as vertical bar. σ is the standard deviation of the symmetric Gaussian blur.

the reference stimulus without SM, and the other one was the test stimulus with SM. The task of the subjects was to see whether these two stimuli were perceived as different.

Stimuli: The stimuli used in the experiment were S3D wave gratings constituted by a S3D image pair. The two S3D images were obtained by applying the Gaussian filter to a sequence of 12 equal-sized vertical stripes of two alternating gray intensities. Reference stimuli with symmetric blur were shown, and they were obtained by using the same standard deviation σ of the Gaussian filter in both S3D images. In the paper, we assume that when σ is zero, the Gaussian kernel is a Dirac delta function, and no blur is introduced. The test stimuli with SM were generated from the reference stimuli, by adding $\Delta\sigma$ to the σ of one of two S3D images of the reference stimuli. The Gaussian filter were applied, because according to [6], defocus-based effects of lens aberrations in images can be modelled with Gaussian blur. Moreover, the stimuli were squared with side length equal to 6 degrees of visual angle. A total of 34 reference stimuli were shown in the experiment. 30 reference stimuli had symmetric blur defined by the standard deviations σ $\{0, 0.5, 1, 2, 5\}$ arcmin, Michelson contrasts $\{0.20, 0.50, 0.98\}$, and disparity equal to zero. The remaining four reference stimuli had no symmetric blur ($\sigma = 0$), Michelson contrast 0.5, and disparities $\{-67.4, 67.4\}$ arcmin. We selected the σ values similar to [7], and we also checked the σ histograms of image datasets [8], [9] to be sure to cover most of the σ values of these datasets. Moreover, we intentionally chose a low, medium, and high contrast. Regarding the disparities, we selected a positive and negative disparity large enough to cover most of the possible disparity range of S3D images.

Procedure: In order to measure the JNSM, we used the method of limits [1]. In the experiment, at the moment when each reference grating was initially shown, the test grating was identical to it ($\Delta\sigma = 0$). At each second, the SM of the test grating was automatically increased by adding 0.07 arcmin to $\Delta\sigma$. The task of the subject was to indicate when she/he started to see a difference between the two gratings.

Apparatus: For the experiment we built a Wheatstone stereoscope [10] in order to avoid any crosstalk. Our stereoscope has two mirrors at 45 degrees fixed on an optical breadboard, two Dell P2415Q monitors, and a chin rest. The effective monitor size is 29.6cm x 52.7cm, the monitor resolution is 3840x2160 pixels, the viewing distance from the monitors is 0.7m, and the visual resolution is 89 pixels/degree. The monitors were carefully calibrated with the X-Rite i1Display Pro colorimeter and the DisplayCAL application. The white point was set to 6500K, the white level to 200 cd/m2, and the gamma to 2.2.

Subjects: In total, 23 subjects, 19 males and four females, took part in our experiment. The subjects were aged between 22 and 52, with an average of 32 years. The subjects had normal or corrected-to-normal vision.

Data Analysis: The JNSM is expressed here as $\Delta\sigma_{JNSM}$ that is equal to the smallest $\Delta\sigma$ that generates a test stimulus perceived differently than the corresponding reference stimulus. The final $\Delta\sigma_{JNSM}$ value is obtained by averaging the subjects' $\Delta\sigma_{JNSM}$ values. Figure 1 shows the plots of the final $\Delta\sigma_{JNSM}$. First, as already observed in [1], the $\Delta\sigma_{JNSM}$ of the gratings with different contrasts are similar. Second, interestingly symmetric blur has an influence on the JNSM: starting from the grating without symmetric Gaussian blur (σ equal to 0) the $\Delta\sigma_{JNSM}$ initially decreases, and around σ 1 arcmin the $\Delta\sigma_{JNSM}$ begins to increase. Third, it can also be observed that the $\Delta\sigma_{JNSM}$ remains nearly constant across different disparities. For this reason, it is not considered in our SM detection method. Based on the large stimuli parameter ranges considered in the experiment, we can conclude that the studied stimuli characteristics do not have a large influence on the JNSM in general.

III. SHARPNESS MISMATCH DETECTION

This section presents a new method under development for the detection of SM in S3D images based on the JNSM.

In the first step, the disparity maps d_{L2R} and d_{R2L} between the left image I_L and the right image I_R are estimated using the Semi-Global Block Matching Approach [11] with consistency check according to [12].

In parallel to the disparity estimation, edge pixels $e_L \in I_L$ and $e_R \in I_R$ are extracted in both images using the Canny edge detector [13]. Then, the edge pixels between the two views are matched, obtaining edge pixel pairs (e^i_L, e^i_R) with $i = 1 \dots N$. Subsequently, for each edge pixel $e^i_{[L,R]}$ the edge width $w^i_{[L,R]}$ and contrast $c^i_{[L,R]}$ are estimated using the

	PLCC	SROCC	RMSE	MAE
CPBD [15]	0.8359	0.587	2.054	1.739
PSM [12]	0.8542	0.5426	1.945	1.599
HSMD [16]	**0.8708**	**0.6296**	**1.839**	**1.455**
Ours	0.8604	0.5496	1.906	1.551

TABLE I: LIVE 3D Phase II dataset [8].

	PLCC	SROCC	RMSE	MAE	OR
CPBD [15]	0.7069	0.4307	5.091	4.192	0.02
PSM [12]	0.9276	0.7572	2.913	2.094	0
HSMD [16]	**0.9548**	**0.8205**	**2.152**	**1.563**	**0**
Ours	0.9217	0.7769	2.944	2.092	0

TABLE II: Ningbo 3D Phase I dataset [9].

method in [14]. The edge width $w^i_{[L,R]}$ is then converted into the standard deviation $\sigma^i_{[L,R]}$ of the Gaussian filter that, when applied to a step edge, generates an edge with the same width.

Next, for each matched edge pixel pair (e^i_L, e^i_R) a local SM criterion Ψ^i is evaluated to check if the SM of the edge pixel pair is larger than the JNSM. In particular, the criterion checks whether the difference $|\sigma^i_L - \sigma^i_R|$ is larger than the $\Delta\sigma^i_{JNSM}$ of an edge with contrast $(c^i_L + c^i_R)/2$ and Gaussian blur standard deviation $min(\sigma^i_L, \sigma^i_R)$. In our method, $\Delta\sigma^i_{JNSM}$ is obtained by bilinear interpolation of the experiment data. The local SM criterion Ψ^i is formally expressed as follows:

$$\Psi^i = \mathbb{1}_{\Delta\sigma^i_{JNSM} \le |\sigma^i_L - \sigma^i_R|}, \qquad (1)$$

where $\mathbb{1}$ is an indicator function, which is equal to one if the condition $\Delta\sigma^i_{JNSM} \le |\sigma^i_L - \sigma^i_R|$ is true, and zero otherwise. Finally, the results of the N local SM criteria are averaged to obtain the final score: S = $\frac{1}{N}\sum_{i=1}^{N}\Psi^i$.

Evaluation: The proposed method was compared against Cumulative Probability of Blur Detection (CPBD) [15], Probability of Sharpness Mismatch (PSM) [12], and Histogram-based Sharpness Mismatch Detection Method (HSMD) [16]. For the evaluation, we used asymmetrically Gaussian blurred images from the datasets LIVE 3D Phase II [8] and Ningbo 3D Phase I [9], together with difference mean opinion scores (DMOS) in the range 0–100. The evaluation consisted in analyzing the correlation between the subjectively obtained DMOS values and the objective SM metric scores. First, the following logistic function was fitted that transforms the objective SM scores to DMOS:

$$DMOS_p(S) = \frac{\beta_1 - \beta_2}{1 + e^{-\frac{S-\beta_3}{\|\beta_4\|}}} + \beta_2, \qquad (2)$$

where $DMOS_p$ is the predicted DMOS of the objective SM score S, and β_{1-4} are parameters that were computed during the fitting. Then, the prediction quality of the logistic function was evaluated based on the following performance metrics: Pearson's Linear Correlation Coefficient (PLCC), Spearman's Rank Ordered Correlation Coefficient (SROCC), Root Mean Squared Prediction Error (RMSE), Mean Absolute Prediction Error (MAE), and Outlier Ratio (OR). Tables I and II show the performance metrics for the two datasets. From the tables, it can be observed that our method is better than CPBD, worse than HSMD, and very similar to PSM.

IV. CONCLUSIONS

This paper presented a psychophysical experiment aimed to study the perception of SM in S3D video. The experiment explored how the minimal amount of SM that is perceived by the human visual system is influenced by contrast, symmetric blur, and disparity. According to the experiment data, none of them has a large influence. Based on the the experiment data, a new method for the detection of SM is presented and compared against state-of-the-art methods. The comparison shows that the proposed method is good but not better than the other methods.

In future work, we plan to improve our method in the following ways: the use of a more accurate estimation method of the edge standard deviation σ, the integration of visual attention to weight regions according to their relevance, and the replacement of the JNSM threshold with the probability of SM perception. The latter requires new experiments to measure this probability.

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