VISUAL DISCOMFORT IS NOT ALWAYS PROPORTIONAL TO EYE BLINKING RATE: EXPLORING SOME EFFECTS OF PLANAR AND IN-DEPTH MOTION ON 3DTV QOE

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ABSTRACT

Visual discomfort is an important factor in determining QoE in 3DTV. It can be measured by physiological signals. In this study, the relationship between 3D video characteristics (e.g., motion type, disparity, velocity, etc), visual discomfort and eye blinking rate were studied. Three motion types were considered, which were static scenes, planar motion and in-depth motion. 44 stimuli with different motion types, disparity levels and velocity levels were studied. The eye blinking signals of 28 observers were obtained by an electrophysiological measurement device. The experimental results showed that stimulus velocity affected eye blinks significantly and differently for planar motion stimuli and in-depth motion stimuli. The objective eye blinking model for 3D stimuli was developed in function of the 3D video characteristics. Furthermore, the results showed that eye blinking rate was proportional to the visual discomfort of the static 3D stimuli but inversely proportional to the visual discomfort of planar motion stimuli.

1. INTRODUCTION

The assessment of Quality of Experience (QoE) for stereoscopic images and video is a challenging issue as it is a multi-dimension index [1]. Visual discomfort is one of the factors that affect QoE significantly. The measurement of visual discomfort can be performed by subjective measurement and objective measurement. Subjective measurement is based on the participant's subjective opinion, e.g., Questionnaire, Paired Comparison test, SSCQE (Single Stimulus Continuous Quality Evaluation), etc. Objective measurement is often based on physiological signals, e.g., eye pressure, blinking rate, electrical activity of the brain, etc. In this study, we focus on the objective measurement.

In the study of [2], the authors used an electroencephalography (EEG) device to detect visual fatigue, the results showed that in the beta band of EEG, the power of the EEG signals in watching 3D video was significantly larger than in watching 2D conditions. In [3], the authors used the functional magnetic resonance imaging (fMRI) to test visual fatigue in 3D condition, the results showed that there were strong activities in the frontal eye field (FEF) which corresponds to eye movement. This result might be an indicator that the eye movement and eye blinks are possible measures for assessing visual fatigue. Nahar et.al [4] studied the electromyography (EMG) response of the orbicularis oculi muscle to different visual stress conditions, the results showed that only for the quint-beneficial test conditions (e.g., refractive error, glare), the power of the EMG response increased with the degree of eyestrain.

Eye blinking rate is considered as an indicator for measuring visual discomfort or visual fatigue. Studies showed that when in relaxed conditions, people would blink more often than in book reading and computer reading tasks [5]. In [6][7], the results showed that blinking rate was higher in watching 3D video than in 2D. The study of [8] gives the conclusion that eye blinking rate increases with visual fatigue when watching 3D images. For the conditions employing visual display unit (VDU), the blinking frequency was significantly decreased during the fatigued behavior (e.g., read information from the screen for a long time) [9]. In conclusion, eye blinking performs quite differently in different conditions, e.g., in relax condition, reading, long term use of VDU, watching 2D images and 3D images.

So far, there is no distinct study on the relationship between eye blinks and controlled visual discomfort stimuli in 3D. In this study, we aim to find out the relationship between eye blinking rate, 3D video characters (e.g., disparity offset, disparity amplitude, velocity, motion type) and visual discomfort.

The rest of the paper is organized as follows. Section 2 introduces the experimental setup. Experimental results and analysis are described in Section 3. Section 4 concludes the paper.

This work has been partly conducted within the scope of the JEDI (Just Explore Dimension) ITEA2 project which is supported by the French industry ministry through DGCIS and the PERSEE project which is financed by ANR (project reference: ANR-09-BLAN-0170).

2. EXPERIMENT

2.1. Apparatus and environment

The Dell Alienware AW2310 23-inch 3-D LCD screen was used in this test (1920×1080 full HD resolution, which featured 0.265-mm dot pitch, 120Hz) with active shutter glasses (NVIDIA 3D vision kit). Viewing distance was about 90 cm. The viewing environment was adjusted according to ITU-R BT.500 [10].

The electro-physiological measurement device Porti from TMSi was used to obtain the EMG signals with eye-blinking data. The sample rate is 2048 Hz. Eight surface electrodes were affixed with conducting paste (Tac-Gel) at the outer canthus, inner canthus, top eyelid and bottom eyelid positions of both eyes. Besides, a reference channel is placed on the forehead about 2 cm above the eyes.

2.2. Experimental design

Three types of 3D motion were considered in this study, planar motion, static situation and in-depth motion. For the planar motion stimuli, we keep them consistent with our previous experiment [11]. Five angular disparity levels were selected which were 0, ±0.65, and ±1.3 degree (+ means crossed, - means uncrossed). A background was placed at a fixed position with the angular disparity of -1.4 degree. Fig. 1(a) shows the disparities used in the planar motion stimuli and their relationship with the comfortable viewing zone (±0.2D for depth of focus). The trajectory of the moving object is a circle with center point at the center of the screen. As the trajectory was a circle, the velocity was expressed in degree/s (circular angle). The three velocity levels were 71.8, 179.5 and 287.2 degree/s (circular angle) which represent slow, medium and fast, respectively. There were in total 15 planar motion stimuli.

For the static condition, five disparity levels were selected which were the same as in the planar motion design. Thus, there were in total five static stimuli.

Three factors were considered for the in-depth motion condition, which were the disparity offset, the disparity amplitude and the velocity. Disparity amplitude represents the difference of angular disparities between the nearest point A and the farthest point B. The disparity offset represents the center of the angular disparities of the two points. The disparity amplitude d_a and the disparity offset d_o can be expressed by Eq.(1), where ϕ_A and ϕ_B are angular disparities of the point A and B.

$$d_a = |\phi_A - \phi_B|, \qquad d_o = \frac{1}{2}(\phi_A + \phi_B) \qquad (1)$$

There were four disparity amplitude levels which were 0.65, 1.3, 2 and 2.6 degree, three disparity offset levels which were -0.65, 0, 0.65 degree, and three velocity levels which were 1, 2, and 3 degree/s (binocular angular degree). There were in total 24 in-depth motion stimuli. The object in the experiment moved forth and back in an endless loop. The three

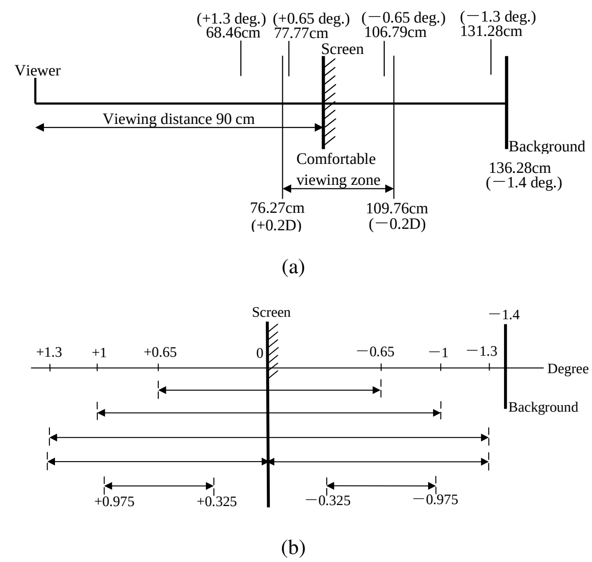


Fig. 1. (a) The relationship of the foreground and the background position and the comfortable viewing zone in planar motion stimuli. (b) The disparity amplitude and offset design in in-depth motion stimuli. The arrow represents the area that the object moves.

velocity levels 1, 2 and 3 degree/s represent slow, medium and fast, respectively. Fig. 1(b) shows the disparity amplitude and offset design for in-depth motion.

2.3. Stimuli

The stereoscopic sequences consisted of a left-view and a right-view image which were generated by the MATLAB psychtoolbox [12]. A black Maltese cross was used as the foreground object with a size of 440×440 pixels (with the visual angle of 7.4 degree). The background was a salt and pepper-like noise image of 1920×1080 pixels. The planar motion stimuli were exactly the same as our previous study [11]. An example of the stimuli is shown in Fig. 2(a). For the static stimuli, the Maltese cross was positioned at the center of the screen, with five disparity levels which are 0, $\pm$ 0.65, $\pm$ 1.3 degree. For the in-depth motion stimuli, the Maltese cross was positioned in the center of the screen and moved forward and backward to the observer. An example is shown in Fig. 2(b).

2.4. Subjects and Procedure

Twenty-eight naive observers participated in this subjective test. All have either normal or corrected-to-normal visual acuity. The visual acuity test was conducted with a Snellen Chart for both far and near vision. The Randot Stereo Test was applied for stereo vision acuity check, and Ishihara plates were used for color vision test. All of the viewers passed the pre-

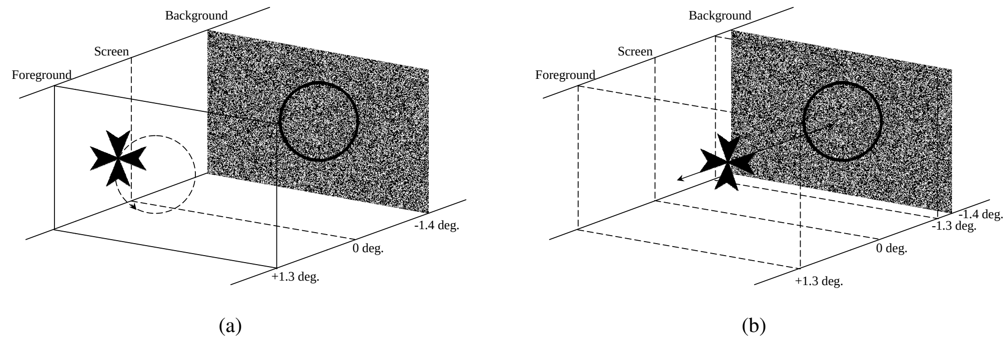


Fig. 2. Examples of stimuli in the experiment. (a) An example of stimulus with planar motion in the experiment. The foreground object is moving at the depth plane with a disparity of 1.3 degree. The background is placed at the depth plane with a disparity of -1.4 degree. The motion direction of the Maltese cross is anti-clockwise. (b) An example of stimulus with in-depth motion in the experiment. The disparity amplitude of the Maltese cross is 2.6 degree, offset is 0 degree. The foreground object is moving in depth between disparity +1.3 to -1.3 degree back and forth.

experiment vision check. Observers were asked to watch each of the stimuli for a duration of 10 seconds. 44 stimuli were displayed. The presentation order was randomly permuted for each observer. EMG signals were recorded from the electrodes.

3. RESULTS

3.1. Influence factors of eye blinking

The EMG signals of the first second and the last second were removed in order to avoid transient effects. The duration of the signals in the analysis was 8 seconds. Eye blinking is easy to detect from the raw EMG signal data according to some criterions. For example, the average length of a blink is 100-400 milliseconds. The amplitude of the blinking signal is much larger than other EMG signal. The same position of the left and right eyes will generate similar responses for eye-blinking. For the position of the top and bottom eyelid, they always generate opposite responses on eye-blinking for the same eye. According to the signals from 8 positions, the numbers of blinks in 8 seconds for all stimuli were counted by manually inspecting the captured signal. The examples of the EMG signal in the top eyelid and bottom eyelid of both eyes are shown in Fig. 3.

The average blinking rate for each stimulus were obtained by averaging all observers' data. It should be noted that the obtained eye blinking rate may be influenced by the electrodes around the eyes. Thus, the eye blinking rate in this paper is not an absolute value. However, in this experiment, due to the fact that all of the data were influenced by the electrodes, these values can be used to make a comparative analysis on the relationship between the eye blinking rate, the 3D video characteristics, and visual discomfort.

The N-way ANOVA test was conducted on the mean blinking rate to test the main factors on blinks for each stimu-

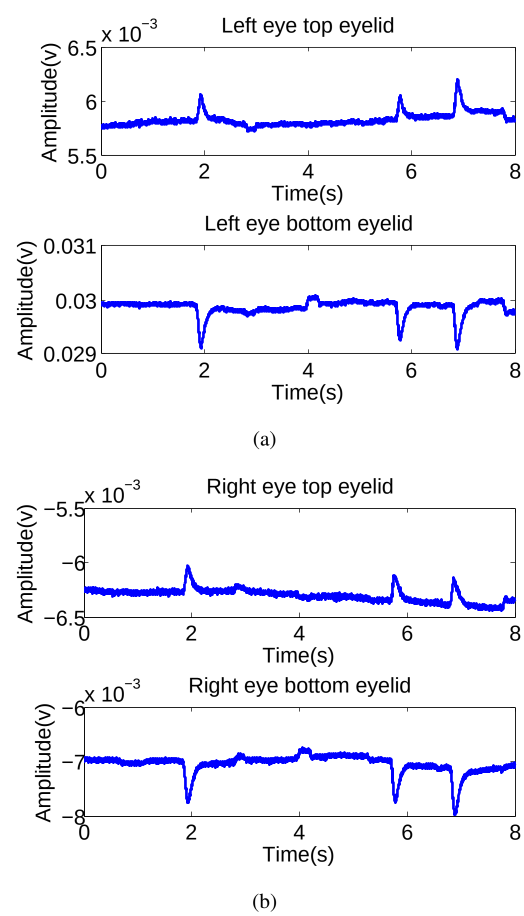


Fig. 3. Examples of the raw EMG signal for the left and right eye at the position of the top and bottom eyelid. Three eye blinks are detected in this example.

Table 1. THE LINEAR REGRESSION RESULTS FOR DIFFERENT MOTION TYPES

Type	Objective model	RMSE	R^2
Static	$0.1752+0.0426r_o$	0.0187	0.8792
Planar	$0.2834-0.0110\,r_o-0.0005v_p$	0.0302	0.7177
In-depth	$0.1345+0.0155r_o-0.0116d_a+0.0184v_d$	0.0258	0.3751

lus condition (for static stimuli, all observers' data were used as the input of ANOVA as only 5 averaged blinking data are not enough for such a test). The results showed that only velocity was the main factor in both the planar motion stimuli and the in-depth motion stimuli, with p-value of 0.005 and 0.0222. The disparity offset for static stimuli, planar motion stimuli and in-depth motion stimuli as well as the disparity amplitude for the in-depth motion stimuli did not have significant influence on eye blinks. The Multiple Comparison test were conducted based on the N-way ANOVA results. The results are shown in Fig. 4. For planar motion and in-depth motion stimuli, only the velocity levels between slow and fast have significant difference. The results indicated that the performances of eye blinks was affected significantly and differently by different video stimuli. Blinking rate increased with velocity when watching in-depth motion stimuli. However, it decreased with increasing velocity when watching planar motion stimuli. Though other factors were tested as not having significant influence on eye blinks, there was a trend of blinking rate with the increase of disparity offset, and this trend was different for different stimuli. For static and in-depth motion stimuli, the blinking rate increased with the disparity offset. However, for the planar motion stimuli, the blinking rate decreased with increasing disparity offset.

As shown in the Fig. 4, the relative disparity between the foreground and the background plays a more important role in eye blinks than the absolute disparity, which shows a strong link with our previous study [11]. With the increase of the relative disparity, the eye blinking rate increases as well for the static and in-depth motion condition. But for the planar motion condition, the results are opposite.

3.2. Objective models for eye-blinking rate

According to the results above, the relationship between eye blinking rate and relative disparity and velocity was nearly linear, thus, the linear regression was used here to generate the objective models for different type of motion stimuli. The regression results are shown in Table 1. r_o represents the relative disparity, d_a represents the disparity amplitude, v_p and v_d are velocities for planar and in-depth motion.

As shown in the objective models, for the static and the in-depth motion stimuli, the relative disparity offset is proportional to eye blinks, i.e., eye blinks increases with the relative disparity. For the planar motion stimuli, the relative disparity is inversely proportional to eye blinking rate. The velocity of the planar motion stimuli is inversely proportional to eye blinking rate while vise versa for the in-depth motion stimuli.

The Root Mean Square Error (RMSE) and R^2 for the observed eye blinking rate and the predicted value are shown in the table as well. The scatter plot of the observed value and the predicted value are shown in Fig. 5. As shown in the results, generally, this model can predict the eye blinking reasonably well, especially in static and planar motion conditions.

3.3. The association of blinking measures and visual discomfort

The visual discomfort score for each stimulus had been previously obtained by a subjective paired comparison method with 42 naive observers. The paired comparison data was converted to visual discomfort scores by the Bradley-Terry model [13]. Bradley-Terry scores are negative values. The higher the value, the higher the visual discomfort degree. The Bradley-Terry scores were considered as the ground truth of visual discomfort in this study. Fig. 6 shows the scatter plot of the mean eye-blinking rate and the visual discomfort score in each type of motion stimuli. The PLCC between eye blinking rate and visual discomfort are 0.9888, -0.8199 and 0.5347 for static, planar motion and in-depth motion stimuli, respectively.

As shown in Fig. 6, the visual discomfort has a linear relationship with eye blinking rate. The linear relation to in-depth motion stimuli is less evident as in the static and the planar motion situation. The results indicated that when watching a still stereoscopic image or 3D video with in-depth motion, the blinking rate increased with the visual discomfort. However, when watching a 3D video with only planar motion, the blinking rate decreased with the visual discomfort.

4. CONCLUSIONS

In this study we analyzed the relationships between eye blinking rate, 3D video characteristics and visual discomfort. The eye blinking signals were extracted from the EMG signal obtained by an electro-physiological measurement device. The N-way ANOVA test results showed that velocity in 3D videos was a main factor for eye blinking and its effect on eye blinks was significantly different for the planar motion stimuli and the in-depth motion stimuli. Eye blink frequency decreased with increasing motion velocity for the planar motion stimuli while it increased for the in-depth motion stimuli. The eye blinking objective model for 3D stimuli was developed which showed relationship between 3D video characteristics and eye blinking rate.

It was also shown that the relationship between eye-blinking rate and visual discomfort was nearly linear. For the static and in-depth motion stimuli, the frequency of eye blinks increased with visual discomfort. However, for the planar motion stimuli, the blinking rate decreased with increasing

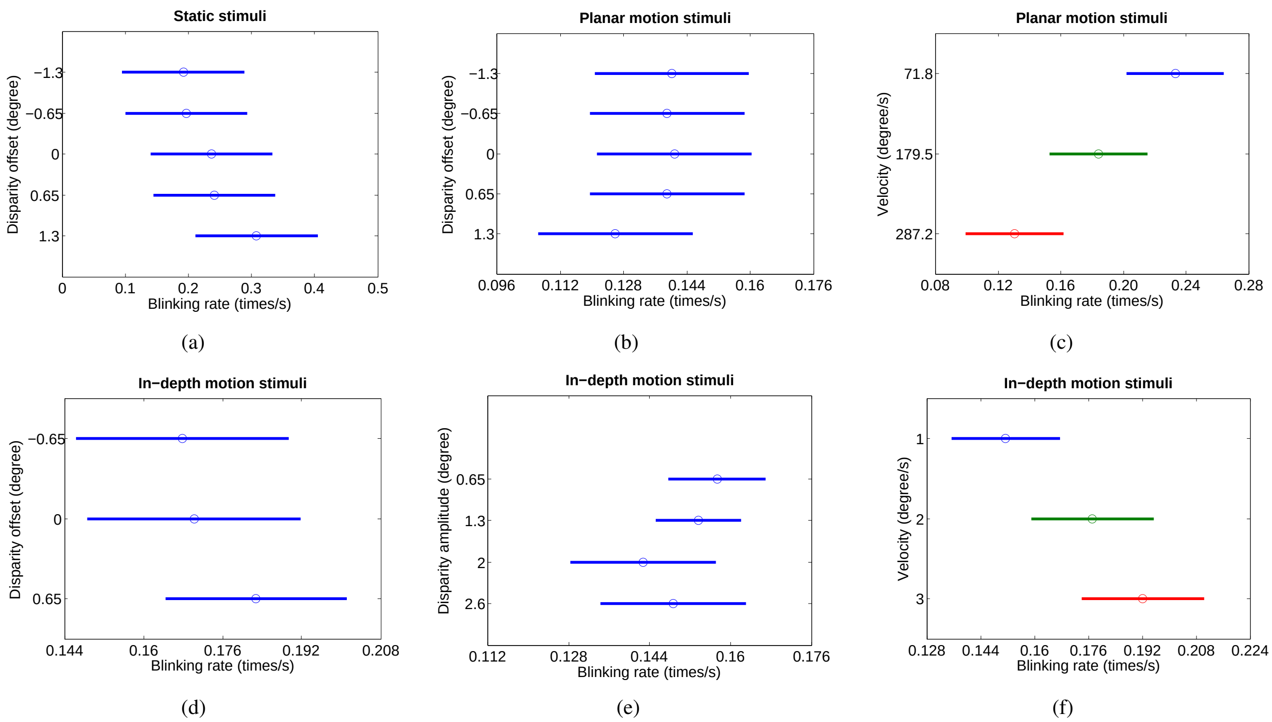


Fig. 4. The Multiple Comparison test results for different factor levels. The mean value and the 95% confidence interval for each level of the factor are provided. (a) is the comparison of disparity offset levels for static stimuli. (b)-(c) are comparisons of disparity offset and velocity for planar motion stimuli, respectively. (d)-(f) are comparisons on disparity offset, disparity amplitude and velocity levels for in-depth motion stimuli, respectively.

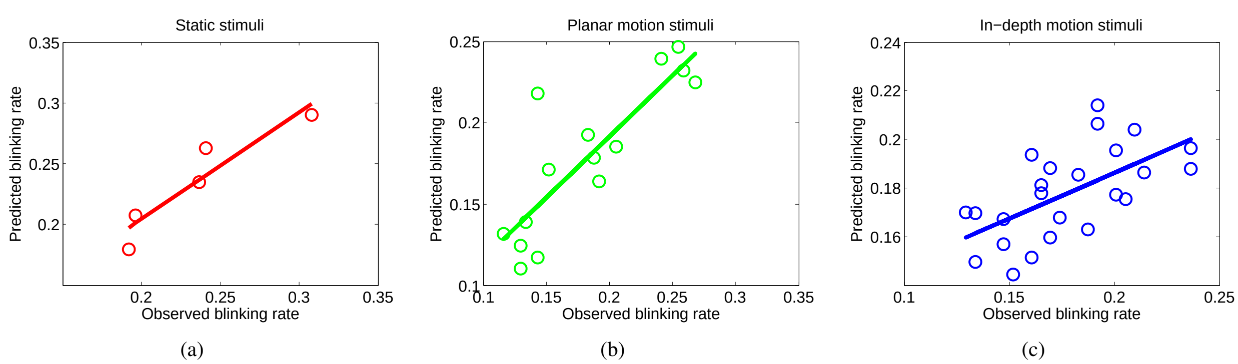
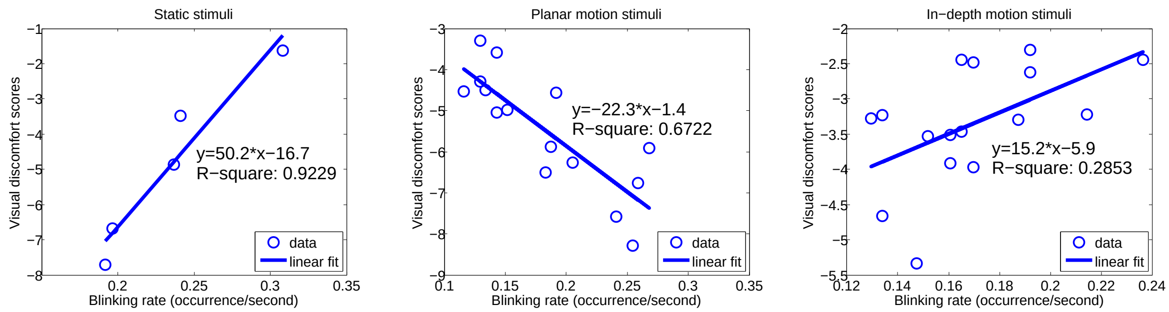


Fig. 5. The scatter plot of the true blinking rate and the predicted blinking rate for all conditions. (a) is for the static stimuli. (b) is for the planar motion stimuli. (c) is for the in-depth motion stimuli.



(a) (b) (c)

Fig. 6. The linear correlation of visual discomfort and eye-blinking rate for static stimuli, planar motion stimuli and in-depth motion stimuli. The x-axis represents the blinking rate. The y-axis represents the visual discomfort degree, higher scores represent more visual discomfort.

visual discomfort. It seems that the blinking mechanisms for planar motion and in-depth motion stimuli are different.

Further study will be focused on the 3D video sequences with natural content. Furthermore, it would be interesting to compare the eye blinking model and the existing objective visual discomfort models[14][15] to investigate and verify their relationships.

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