PRJ7-4
Invited

Research on Measuring Methods of Immersion for Virtual Display

BO Qiao[1], Yang Pan[1], Guanxiong Pei[1], Taihao Li[1], Shuai Yao[1]

qiaob@zhejianglab.com
[1]Zhejiang Lab
Keywords: measuring methods, immersion, virtual display

ABSTRACT

Immersion is an important parameter to characterize the performance of virtual display in interaction. In this study, we proposed a measuring methods of immersion for virtual display based on neurocomputing method. By comparing with self-report method, the consistency index was at a relatively high level, which indicates that EEG-based affective computing offers an option to evaluate the immersion of virtual display.

1 Introduction

Compared with the traditional display technology based on real image, the biggest difference of VR/AR/MR use the virtual image to simulate the real scenes, so that people can get sensory satisfaction in the virtual world. This makes the experience of immersion especially important in the process of interaction. However, due to the influence of image quality, head tracking, virtual hand/body, continuity of response, social and other factors, the immersion of virtual display is poor, easy to vertigo and other problems have not been solved.

1.1 What is the Immersion

According to some research, immersion refers to making individuals focus on the current target situation, participate and substitute into the cognitive absorption and emotional arousal to the target situation, and forget the real external environment. There is a direct relationship between physiological change and the feeling of immersion[1].

1.2 Current Situation

At present, the focus of immersion assessment is mainly on indirect parameters, such as optical performance and image quality. In IEC 63145, measurement methods of field of view, pixel angular density, distortion, flick, positioning accuracy and other parameters have been defined. Of course, these parameters are important and can have an impact on immersion, but these can't achieve the quantitative evaluation of immersion.

Also, several studies have implemented questionnaires to make assumptions about the user's experience while in the virtual environments[2-3]. However, due to individual differences in questionnaire responses, subjectivity of understanding and feeling of questions, interference of surrounding environment, and non-real-time, this method can only carry out qualitative characterization to a certain extent, rather than quantitative evaluation. Thus, we should use a new method based on physiological evidence to evaluate immersion.

1.3 Measuring Methods of Immersion

Usually, the physiological signals include EEG, ECG, galvanic skin responses and so on [4]. Among them, EEG has strong correlation with brain activity, high time sensitivity, strong anti-interference, difficult to camouflage and other excellent performance, so it is known as the gold index of human body state monitoring.

For EEG signal, there are five frequency bands that are usually used, namely, δ(0.5-4Hz)、θ(4-8Hz)、α(8-13Hz) 、 β(13-30Hz) 、 γ(30-60Hz). Among them, θ represents the degree of immersion and concentration, and there are strongly correlated with individual attention. α represents the connection between conscious and unconscious thoughts, helping people calm down when necessary and promoting relaxation and rest. β represents brain consciousness, logical thinking and stress response activities, which are closely related to the excitement level of an individual. In this study, we use emotional arousal and cognitive absorption to represent immersion.

By using a multi-channel EEG device to capture EEG signals from different brain regions, we can create a signal matrix that includes time domain signal, frequency domain signal, time-frequency domain signal and nonlinear signal. By processing the above signals and matrix operation, we can use Equations 1 and 2 to calculate the emotional arousal (*EA*) and cognitive absorption (*CA*) of the subject:

$$EA = \frac{\bar{P}_\beta}{\bar{P}_\alpha} = \begin{bmatrix} S_1V_1 & \cdots & S_1V_{15} \\ \vdots & \ddots & \vdots \\ S_{25}V_1 & \cdots & S_{25}V_{15} \end{bmatrix} \quad (1)$$

$$CA = \frac{\bar{P}_\beta}{\bar{P}_\alpha + \bar{P}_\theta} = \begin{bmatrix} S_1V_1{}' & \cdots & S_1V_{15}{}' \\ \vdots & \ddots & \vdots \\ S_{25}V_1{}' & \cdots & S_{25}V_{15}{}' \end{bmatrix} \quad (2)$$

$\bar{P}_\alpha$ is mean values of power *P* in α bands at two electrode points（F7 and F8), $\bar{P}_\beta$ is mean values of power P in β bands at two electrode points（F7 and F8), $\bar{P}_\theta$ is mean values of power P in Θ bands at two electrode points（F7 and F8), S_mV_n is the power ratio of $\bar{P}_\beta$ to $\bar{P}_\alpha$ when the No.m subject watches the No.n test pattern, S_mV_n' is the power ratio of $\bar{P}_\beta$ to $(\bar{P}_\alpha + \bar{P}_\theta)$ when the No.m subject watches the No.n test pattern.

2 Experiment

We designed the following experiment to collect the EEG signals of the subjects when they were wearing a virtual display device to watch the video, and calculate emotional arousal (*EA*) and cognitive absorption (*CA*).

2.1 Equipment

We choose HTC VIVE PRO EYE(VIVE-P130) as virtual display. And we use BP EEG measurement system with 32 channels (international standard 10-20 system) for EEG recording. The setup of experimental equipment as shown in Fig. 1.

Fig. 1 Setup of experimental equipment

2.2 Subjects

A total of 25 subjects participated in this experiment. All subjects were right-handed, had normal vision or corrected vision, had no color blindness or weakness, had no history of mental illness or other craniocerebral disease or trauma. This study was approved by the ethics committee.

2.3 Process

The subjects need to watch 15 VR videos for 30 seconds each. An blank screen for 30 seconds was placed between each two videos to erase the subjects' emotions and give them a rest. At the beginning of the experiment, there will be an blank screen for 30 seconds to facilitate the subjects to enter the test state. The total time of data collection in the formal experiment is 15 minutes. At the same time, due to the synchronous wearing of EEG cap and VR glass, the head of the subjects was under great pressure. The subjects were told that they could relax properly and make small body posture adjustment in the blank screen stage if they really felt uncomfortable. The EEG maintained real-time signal acquisition throughout the experimental test.

2.4 Key Problems in Experiment

In this experiment, there are some key problems that need to be paid attention.

1. **Test pattern**. Test pattern(video image) is the core element of virtual environment construction. Video images with different contents have different emotional stimulation and immersion impressions on people. Therefore, we selected different types of video as test pattern, involving positive, negative and neutral emotions. The average valence value of 15 videos is 5.26 (SD=1.17, MIN=3.56, MAX=7.48). The coefficient of variation is 22.3%. There are obvious differences of valence between varied videos.

2. **Audio**. This experiment mainly uses VR video images to build a virtual environment. Therefore, in order to reduce the impact of external input on immersion, this experiment adopts audio-free video images(test pattern), and the whole experiment is also carried out in an acoustic environment.

3. **Real-time response of questionnaire**. In order to verify the validity of this experiment, we adopted the method of comparison and verification between subjective evaluation and this objective experiment. Subjective evaluation was scored by Likert nine-point scale. Therefore, in order to ensure the real-time synchronization of subjective and objective evaluation in the time dimension, we built the Likert nine-point scale into the virtual display device. After viewing each video, the subjects rated the Likert scale.

4. **Transient emotional waves and facial movements**. During the test, the subjects would have redundant movements such as head movement, clenching teeth, swallowing saliva, etc., which would lead to head muscle discharge and result in excessive deviation of EEG. We use the RAW data Inspection tool to remove artifacts. In the process of the experiment, the inevitably blink of the subjects causes the facial and forehead muscles to discharge. The electrooculographic activity was recorded and we used RAW data Inspection semi-automatic and semi-manual method to correct the blink artifact.

3 Results

We collected EEG spectrum data from 25 subjects as they watched 15 videos(test patterns).

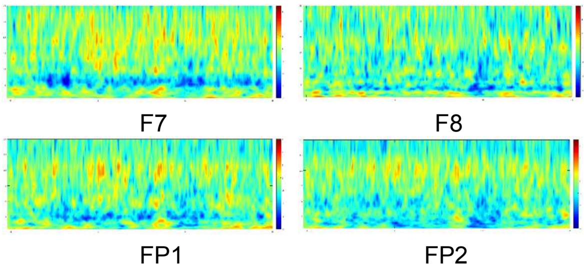

Fig. 2 Spectrum of subjects watched the No.1 video

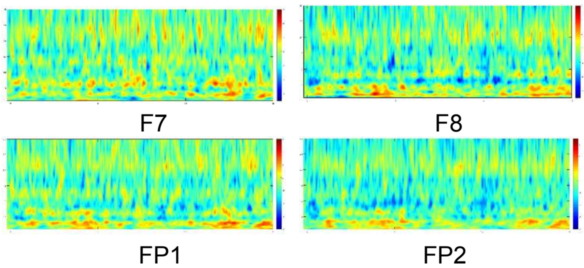

Fig. 3 Spectrum of subjects watched the No.15 video

4 Discussion

Through the comparison of objective measurement and subjective evaluation, we verify the effectiveness of the above measuring method of immersion. Subjective evaluation was scored by Likert nine-point scale, with 1 representing the lowest emotional arousal/cognitive absorption, and 9 representing the highest.

We recorded the emotional arousal scale scoring data of 15 test patterns of 25 subjects (scored by Likert 9-point scale) as N_A. Then, *EA* and N_A are normalized to make all data distributed at [0,1]. Fourth, we rotated the matrix *EA*. Find the orthogonal matrix *Q*, such that *Q* is the solution to the Equation 4:

$$\begin{cases} min\|Q * EA - N_A\|_F^2 \\ s.t. Q^T Q = I \end{cases} \quad (4)$$

We analyzed the column trend consistency of *Q***EA* and matrix N_A, and the results show that the consistency index is 72.29%.

We recorded the cognitive absorption scale scoring data of 15 test patterns of 25 subjects (scored by Likert 9-point scale) as N_C. Then, *CA* and N_C are normalized to make all data distributed at [0,1]. Fourth, we rotated the matrix *CA*. Find the orthogonal matrix *Q*, such that *Q* is the solution to the Equation 5:

$$\begin{cases} min\|Q * CA - N_C\|_F^2 \\ s.t. Q^T Q = I \end{cases} \quad (5)$$

we analyzed the column trend consistency of *Q***CA* and matrix N_C, and the results show that the consistency index is 77.14%.

5 Conclusions

Self-report data shows that the immersion score has a high correlation with cognitive absorption and emotional arousal scores. Thus, the immersion of virtual display can be evaluated through EEG-based neural calculations. Its advantage lies in the simultaneous measurement and objective diagnosis, which to a certain extent solves the problems of post-measurement by means of questionnaire measurement, social desirability bias, and subjectivity.

References

[1] Baumgartner, T., Valko, L., Esslen, M., & Jäncke, L. (2006). Neural correlate of spatial presence in an arousing and noninteractive virtual reality: an EEG and psychophysiology study. CyberPsychology & Behavior, 9(1), 30-45.

[2] P. Renaud, S. Bouchard and R. Proulx. Behavioral avoidance dynamics in the presence of a virtual spider. Information Technology in Biomedicine, IEEE Transactions On 6(3), pp. 235-243. 2002.

[3] B. G. Witmer and M. J. Singer. Measuring presence in virtual environments: A presence questionnaire. Presence: Teleoperators and Virtual Environments 7(3), pp. 225-240. 1998.

[4] Marín-Morales, J., Higuera-Trujillo, J. L., Greco, A., Guixeres, J., Llinares, C., Scilingo, E. P., ... & Valenza, G. (2018). Affective computing in virtual reality: emotion recognition from brain and heartbeat dynamics using wearable sensors. Scientific reports, 8(1), 1-15.