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ScienceDirect
Displays 29 (2008) 176–183
DISPLAYS
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Time–frequency structure of image motion vectors around cybersickness intervals determined with biosignals

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Available online 22 October 2007

Abstract

Vection-inducing or shaky video images sometimes cause visually induced motion sickness (cybersickness). We determined potential cybersickness intervals and trigger points with biosignals and analyzed video images with the motion vectors. For video images that strongly induced cybersickness, zone intervals with a high correlation coefficient between local and global motion vectors were located at the peaks of trigger points in the time-distribution obtained from 25 subjects. Around the trigger points, the time–frequency structure of global motion vectors included temporal frequencies ranging from 0.3 to 2.5 Hz. This approach will be useful for predicting trigger points in video images from only motion vectors.

Keywords: Cybersickness; Autonomic nervous regulation; Image motion vector; Time–frequency structure

1. Introduction

These days, many people use brand-new digital imaging technology such as movie applications in PCs and hand-held video cameras. However, uncontrolled usage increases the chance of unwanted visual stimuli spreading widely via broadcasting channels including the Internet. Regarding image safety, Harding [1] analyzed video image factors that evoked photosensitive seizures and produced a screening instrument. He pointed out that flashing and some specific patterns had bad influences on the brain. Another problem is visually induced motion sickness. For example, viewers sometimes feel an unpleasant sensation when viewing unexpected off-centered or shaky images taken by an amateur with a hand-held video camera.

Practical problems are emerging not only in personal entertainment, but also in applications of virtual reality (VR) and virtual environments (VEs). VR is a promising technology for expanding our sensory and physical functions, and applications are penetrating telemedicine and rehabilitation engineering [2]. Nevertheless, there are some problems in relation to sickness discomfort and aftereffects due to visual stimuli, such as visually induced illusions of self-motion (vection). In relation to motion sickness, it has been supposed that the mismatch between the visual and vestibular cues causes visually induced motion sickness [3–7]. The visually induced motion sickness in VR or VEs has been referred to as "cybersickness" since the early 1990s [6]. Cybersickness symptoms produce more disorientation and nausea than oculomotor-related symptoms, and moving for more than 10 min causes significant increases in nausea ratings [8,9]. In the late 1990s, Stanney et al. [10] reviewed human factor issues in VEs and Cobb et al. [11] summarized VR-induced symptoms and effects in a variety of VR systems. Then, Nichols et al. studied associations between presence and sickness [12] and pointed out some

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doi:10.1016/j.displa.2007.10.005

health and safety implications of VR to make recommendations regarding the future direction of VR [13]. However, details in relation to the visual factors and self-conditions that could significantly contribute to cybersickness are still unknown.

Studies on cybersickness have appeared in three major fields related to display devices and images, sensory and cognitive systems, and autonomic regulation. To evaluate the effects caused by display devices and images, geometric pattern or optical flow images produced by an optokinetic rotating drum and virtual images produced by computer graphics have been used [4,11,14,15]. So et al. [16] proposed a metric for quantifying virtual scene movement by spatial velocity as an important contributing factor in cybersickness, but the images were virtual scenes. There have been a few studies in quantifying real video image features as visual stimuli [17]. Study on sensory systems with eye movement [15] showed that subjects with poor visual acuity experienced greater visually induced motion sickness and visual fixation reduced sickness, but vection was unaffected. Neuroscientific models [7,18] further dealt with vestibular and proprioceptive inputs in relation to sensory conflict or sensory rearrangement, suggesting the influences of vestibular-autonomic responses on motion sickness. In addition to the visual stimuli, unpleasant sensations for individual subjects have been assessed by autonomic-nervous-activity-related objective indices with a relatively long time-scale: they have been estimated from biosignals including heart rate, blood pressure, finger pulse volume, respiration rate, skin condition, and gastric myoelectrical activity [19–21]. On the other hand, there is a popular subjective index: the Simulator Sickness Questionnaire (SSQ) [22]. The total SSQ score is a combination of components based on the levels of nausea, oculomotor problems, and disorientation.

We focused on the relationship between the video image features associated with visually induced motion and the autonomic nervous regulation and tried to determine the factors that cause cybersickness quantitatively. We quantified real video image features with camera motion estimated by image motion vectors [17]. The motion vector is superior in terms of wide applicability for all types of images including real and virtual images. Since it is used in image data compression as a key technology, it is also convenient for surveying digital video images transmitted via the Internet. To assess the autonomic nervous regulation, we measured a subject's electrocardiogram (ECG), blood pressure, and respiration, while he/she was watching video images from the first-person view. The potential cybersickness intervals were extracted by analyzing biosignals and the onsets of visually induced sensation were determined in the autonomic-nervous-activity-related index backwards in time. We then investigated the specific time–frequency structure of motion vectors around triggered onsets that caused cybersickness [23].

2. Methods

2.1. Evaluation of cybersickness

Since Akselrod et al. [24] reported the relationships between autonomic nervous activity (ANA) and the powers of specific frequency ranges in the R–R interval time-series, the powers of specific frequency ranges are widely used as ANA-related indices. We used the power in limited frequency ranges of blood pressure, respiration, and R–R interval. In practice, we estimated the time-varying behavior of ANA-related power indices in the limited frequency ranges by using the continuous wavelet transform (CWT) [25]. In order to divide a frequency region of interest, $[f_{\min},f_{\max}]$, into I small frequency ranges on a logarithmic scale (constant – Q), the center frequency $f_{c,i}$ in the ith frequency range is given by

$$f_{c,i} = f_{\min}\left(\frac{1}{1-r}\right)^{i-1}, \quad i = 1,2,\ldots,I. \tag{1}$$

Therefore the frequency region of interest is composed of band-pass filters with constant relative bandwidth of $2r$. As a mother wavelet we used the Gabor function

$$\psi(t) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{t^2}{2\sigma^2} + \mathrm{j}\omega_c t\right), \tag{2}$$

which includes an expansion parameter σ and ω_c is equal to $2\pi f_c$.

The sampling rate of biosignals was adjusted to the frame rate of video images. Since the frame rate was 30 frames/s, we uniformly resampled the interpolated R–R interval time-series at a frequency of 30 Hz. We calculated the averaged blood pressure for maximum and minimum values within the R–R interval as the blood pressure time-series. The blood pressure and respiration were also resampled at 30 Hz. In the extraction of ANA-related indices, all of the time-series were normalized $N(0,1)$ to enable us to neglect the difference in scales. The limited frequency ranges were 0.04–0.15 Hz with $I = 7$ for blood pressure and R–R interval (Mayer wave related signal) and 0.15–0.45 Hz with $I = 6$ for respiration and R–R interval (respiratory sinus arrhythmia related signal) [26]. Thus, we obtained the time-series of the ANA-related indices every frame with a 10-s interval.

To extract the potential intervals that cause cybersickness, we surveyed the time-varying behavior of the ANA-related indices and individual self-reports. Then we set up threshold levels for the low-frequency (LF) power and the high-frequency (HF) power of the fluctuation of biosignal time-series. That is, after estimating the averaged LF and HF power components during a 3-min rest period ahead of visual stimuli for individual subjects, we extracted a potential cybersickness interval based on the following ANA-related conditions [17,23]: the LF power component is greater than 120% of the averaged LF power component, LF120, and the HF power component is less than 80% of