A PROGRESS REPORT ON THE QUEST TO ESTABLISH A CYBERSICKNESS DOSE VALUE

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This paper summarizes the progress made in the quest to establish a Cybersickness Dose Value (CSDV). The Motion Sickness Dose Value (MSDV), reported in the British Standard BS6841, has been used to predict the severity of seasickness since 1987. In 1999, the authors of this paper proposed a CSDV formulation with a structure similar to that of the MSDV (So, 1999). Since then, several experiments and simulation studies have been conducted to modify and develop the proposed CSDV formula. In particular, progress has been made in (i) the methods to measure CSDV, (ii) the determination of a frequency weighting curve to equalize the non-linear relationship between the navigation velocity and levels of cybersickness, and (iii) the detailed formulation of CSDV. This paper summarizes the past progress and reports on the current effort in developing a CSDV.

INTRODUCTION

The causes of cybersickness (a type of motion sickness associated with the use of virtual reality (VR) systems, McCauley and Sharkey, 1992) have been the focus of many studies. Factors like duration of exposure (Regan, 1995), display time delays and field-of-view (DiZio & Lackner, 1997) have been found to affect significantly the severity of cybersickness. Nonetheless, a formula has not been derived to predict the average severity of cybersickness associated with exposure to a VR simulation of known duration, display time delays, and field-of-view. The research coming closest to this goal is by Kolasinski (1995). She reported a regression model to predict the severity of cybersickness as a function of individual factors such as gender, age, and scores on postural tests. However, Kolasinski's work did not focus on the factors associated with the visual stimuli in a VR simulation. In 1999, one of the authors of this paper proposed a Cybersickness Dose Value (CSDV) to predict the average severity of cybersickness associated with a particular VR simulation (So, 1999). The proposed CSDV formula was based on the finding that cybersickness is a type of vection-induced motion sickness and visual scene movement is the main cause of the sickness (Hettinger and Riccio, 1992). The proposed CSDV formula is as follows:

\[ CSDV = \int [frequency \; weighted \; SV] \, dt \]

where \( SV \) is a proposed metric called spatial velocity.

\( SV \) quantifies the amount of visual scene movements that an operator will have perceived during a VR simulation. This paper presents progress on the development of this CSDV formula since 1999.
PROGRESS IN MEASURING SPATIAL VELOCITY (SV)

The proposed SV metric has two components: (i) scene complexity perceived by the participants during the VR simulation and (ii) velocity of navigation during the VR exposure (So et al., 2001).

Measurement of the Scene Complexity Component

The scene complexity perceived by participants during a VR simulation is measured as the average spatial frequencies (SFs) in the horizontal, vertical, and radial axes (So et al., 2001). These three average SFs are calculated from sampled snapshots of the virtual environment (VE) along the navigation path. The use of SF in quantifying the scene complexity of a visual field has been a standard in studies on motion sickness induced by vection drums (e.g., Hu et al., 1997). So et al. (2001) extended that idea to quantify the scene complexity of a VR simulation. To calculate the three average SFs of the whole VR simulation, the SFs in the horizontal, vertical, and radial axes of each sampled snapshot are calculated before the averages are taken. The details of the SF calculations can be found in So et al. (2001). The proposed sampling rate is two snapshots per second. The method for calculating the SFs of a single snapshot is available on the Web. Readers may try this program by loading a captured snapshot of their virtual environments (VEs) onto www.cybersickness.org.

Measurement of the Navigation Velocity Component

The navigation velocity component is measured by calculating the root-mean-square values of the scene movements on six different axes (vertical, lateral, fore-and-aft, pitch, yaw, and roll; So et al., 2001). In the So et al. (2001) study, spatial velocity (SV) for all six axes was measured because the effects of navigation axes on cybersickness were not known.

The search for dominant axes

Two experiments have been conducted to investigate the effects of scene movements along different axes on the levels of cybersickness. Lo and So (2001) reported that scene oscillations in a virtual environment (VE) along the pitch, yaw and roll axes can significantly increase both the nausea rating and Simulator Sickness Questionnaire (SSQ) scores. However, there is no significant difference among the severity of the sickness associated with scene movements in the three rotational axes. In other words, a dominant rotational axis of virtual scene movement could not be found. Chen and So (2002) reported on a study conducted to investigate the effects of scene movements along different translation axes. Initial results indicated that scene movements in all three translational axes can significantly increase the levels of cybersickness. The severity of the sickness associated with scene movements on the lateral axis is significantly higher than that on the other two axes.

PROGRESS IN ESTABLISHING THE RELATIONSHIP BETWEEN SEVERITY OF CYBERSICKNESS AND THE PROPOSED CSDV

Between 1999 and 2002, several experiments were conducted to investigate the relationships between $\int SV dt$ and the severity of cybersickness. Subjects were asked to take the pre-exposure SSQ and then they were immersed in a VE for 20 or 30 minutes. During the exposure, nausea ratings were obtained verbally every five minutes. After the exposure, subjects were asked to complete a post-exposure SSQ. Both SSQ scores (Kennedy et al., 1993) and nausea ratings (Golding and Kerguelen, 1982) were used to measure the severity levels of cybersickness. Due to the space limit, only the nausea rating data are discussed here.
Nausea rating as a function of $\int SVdt$ with eight levels of scene velocity

So et al. (2002) studied the effects of navigation velocity on cybersickness. Eight different navigation velocities were used. Results showed that nausea ratings increased as navigation velocity increased from 3 m/s to 10 m/s. Beyond 10 m/s, the nausea ratings became stable. Figure 1 illustrates the effect of $\int SVdt$ in the fore-and-aft axis on nausea ratings at the end of a 30-minute VR simulation. Although scene movements on the lateral axis have been shown to have significantly stronger influence on cybersickness than do scene movements on the other translational axes (Chen and So, 2002), $\int SVdt$ on the fore-and-aft axis is still used for illustration because most of the navigation movements were on the fore-and-aft axis (So et al., 2002).

The variations in the spatial velocity (SV) are due to changes in navigation velocity. Each data point is the mean data of 12 participants (data from So et al., 2002).

Nausea rating as a function of $\int SVdt$ with eight levels of scene complexity

Yuen and So (2002) reported results of two experiments conducted to investigate the effect of scene complexity on cybersickness. The first experiment used three virtual environments (VEs) of a metropolitan city with different levels of scene complexity and the second experiment used five VEs of a sea-front with different levels of scene complexity. The two experiments had 116 participants. The mean nausea rating data of the first 58 participants are shown in Figure 2 as a function of $\int SVdt$.

Data obtained in 2 experiments. ‘△’ represents data obtained after navigating at 9.5 m/s through 3 virtual cities of different scene complexities. ‘●’ represents data obtained after navigating at 27.5 m/s through 5 virtual seafronts of different scene complexities (adopted from Yeun and So, 2002).
Initial results showed that the severity of cybersickness increased sharply as $\int SVdt$ increased from 0 to 5K metre x cycle per degree (Mcpd). Beyond 5K Mcpd, the severity of cybersickness increased at a slower rate. The nausea ratings were obtained at the end of the 30-minute VR simulations.

SSQ data also showed similar results.

**PROGRESS IN DEVELOPING A FREQUENCY WEIGHTING CURVE**

Figure 1 shows that the effects of scene velocity on cybersickness are not linear. Moreover, Figure 2 indicates that nausea ratings increase with increasing $\int SVdt$ at different rates when the navigation velocities are different. A frequency weighting curve to equalize the non-linear relationship between scene velocity and cybersickness is needed. A careful examination of the study reported by So et al. (2002) indicates that the eight different navigation velocities were, in fact, eight different frequencies of navigation. Participants in the eight conditions with different velocities navigated through the same VE along the same path but at different speeds. This is analogous to a sine-wave oscillation with the same amplitude but different ‘speeds of oscillation’ (i.e., frequencies). Consequently, Figure 1 can be redrawn with navigation frequencies on the horizontal axis. Following the method used to develop the frequency weight curves for human hearing (e.g., Berger et al., 1986) and the frequency weight curve ($W_f$) for ship motion causing seasickness (e.g., British Standard Institution, 1987; Griffin, 1990), a frequency weighting curve is now being derived.

**CONCLUSIONS AND FUTURE WORK**

Results from six individual studies with ten different VEs (Lo and So 2001, 1 VE containing buildings, tracks and bridges; Yuen and So 2002, 3 VEs of a metropolitan city and 5 VEs of a sea front; Chen and So 2002, 1 VE of an indoor scene), 14 different navigation velocities, and more than 200 participants have confirmed that the severity of cybersickness increased rapidly with increasing $\int SVdt$ in the fore-and-aft axis until a threshold was reached beyond which the sickness severity began to stabilize. Data are available to develop a frequency weighting curve to equalize the non-linear relationship between sickness ratings and scene movement velocity. Among the scene movements in the three rotational axes, a dominant axis could not be found. Among the scene movements in the three translational axes, initial results indicated that scene movements on the lateral axis were associated with the strongest levels of sickness. This paper reports on progress in developing a Cybersickness Dose Value (CSDV) between 1999 and 2002. The work is continuing and the authors would like to invite international collaborators to join in the quest to develop a CSDV for predicting the severity of cybersickness. To facilitate potential collaborations, the algorithms to calculate the average ‘spatial velocities’ (SVs) of a captured snapshot of a VE are available at www.cybersickness.org.

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