

Evaluation of Visually-Controlled Task Performance in Three Dimension Virtual Reality Environment

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Abstract. The present study aims to evaluate three commercial VR display devices on the market via a 3D Fitts' task. In addition, a Simulation Sickness Questionnaire (SSQ) was used to assess simulator sickness of participants. Ten participants performed repetitive pointing tasks over different conditions of varying display devices, movement directions and indices of difficulty. Based on the results, it seems that the 3D TV technology may not provide enough perceptual depth to enhance movement performance in a 3D VE. The projection display obtained the best performance and preference among the three display devices. The HMD gave the worst result in both the experimental task and the SSQ assessment due to the accompanied discomfort and fatigue.

Keywords: Fitts' law, virtual reality, projection display, HMD, 3D TV.

1 Introduction

Virtual Reality (VR) is a modern technology in the computer science field that offers huge potential impact at home, workplace and schools. Since inducted in 1960's, it has come up in a major way as architecture, interior design, medical, education, training and so forth. In the early period, more attention has been paid to development of the technology itself and potential application uses, but until recently little research and literature has been reported on usability and ergonomic issues associated with VR.

Virtual Environments (VE) can be described as computer-generated immersive surroundings where participants feel to be present and can interact intuitively with objects. The hardware of a typical immersive VR system will include: a computer, a display device and a hand-held input device. As the progress of computer technology, there are plenty of display devices on market could be adopted to present 3D virtual environments. However, the performance enhancement, comfort and fatigue of using these display devices to present a 3D VE are still indeterminate.

The 3D stereo television (3D TV) technology introduced by Philip [1] in 2006 is a breakthrough. This autostereoscopic 3D display provides stereo image that do not require users to wear special 3D glasses. However, in an interactive VE, the impact of the 3D TV on human motor performance is still unclear. For this reason, we apply Fitts' Law to this evaluation.

Fitts' Law [2] is well known to be an effective quantitative method for modeling user performance and evaluating manual input devices. Fitts' Law states that the time to move and point to a target of width W at a distance A is a logarithmic function of the spatial relative error (A/W), as shown in Equation (1).

$$MT = a + b \log_2(2A/W) . \quad (1)$$

where a and b are empirical constants determined through linear regression. The \log term is called the index of difficulty (ID) and describes the difficulty of the motor task (bits).

Some variations of the law have been proposed, such as the Shannon formulation [3]. This equation (Equation (2)) differs only in the formulations for ID.

$$MT = a + b \log_2(A/W + 1.0) . \quad (2)$$

The benefit of this equation is that it provides the best statistical fit, reflects the information theorem underlying Fitts' law, and always gives a positive ID. The throughput (TP) proposed by ISO [4] is the most familiar performance measurement of information capacity of human motor system. This approach combines the effects of the intercept and slope parameters of the regression model into one dependent measure that can easily be compared between studies [5]. As shown in Equation (3), MT was the mean movement time for all trials within the same condition, and $ID = \log_2(D/W+1)$.

$$\text{Throughput} = ID/MT . \quad (3)$$

Fitts' Law is an effective method in evaluating input devices. However, it has rarely been applied in comparing visual display devices. Fitts' pointing paradigm is a visually-controlled task, hence either input devices or display devices could influence performance of human motor system. In order to test whether Fitts' Law is applicable to compare display devices, Chun et al. [6] used Fitts' Law to evaluate four 3D stereo displays with same haptic input device. The results of this study demonstrated that Fitts' Law was applicable to the evaluation of visio-haptic workstations.

Except performance measurement, subjective questionnaires were usually used to measure discomfort resulted from display devices in virtual reality environment. In 1997, Howarth and Costello [7] proposed a Simulation Sickness Questionnaire (SSQ) to compare head mounted display (HMD) and visual display unit (VDU). The results showed that HMD was rated with high scores than VDU in fatigue, headache, nausea and dizziness.

In summary, the present study attempts to evaluate the 3D TV and other two familiar display device, HMD and projection display, via Fitts' task and Simulator Sickness Questionnaire. From the results of this study, it will be shown that how is the influence of these three displays on human motor performance.

2 Methods

2.1 Subjects

Ten right-handed adult subjects participated in this experiment, aged 20-30 years old (six males and four females, mean age = 26.7 years, SD = 2.8 years), and were undergraduate Industrial and Systems Engineering students of Chung Yuan Christian University. All subjects had normal or corrected-to-normal vision with no other physical impairments.

2.2 Apparatus

Three display devices were used to present virtual reality interactive environment. The first display device adopted is the 3D stereo television (Philips 42" WOWvx). As illustrated in figure 1, the 3D TV is to get a distinct image into each eye of the viewer. From that point, the viewer's brain takes over, processing each image in the same, natural way in which it processes the images it receives from the three-dimensional world. The resolution of 3D TV is 1280×1024 pixels and refresh rate was 60 Hz. It is located in front of subjects in 1.5 meters and the field of view estimated is 32.8 degree.



Fig. 1. 3D stereo television Philips 42" WOWvx [1]



Fig. 2. Head mounted display i-glasses VIDEO 3D Pro [8]

The second display device head mounted display (i-glasses VIDEO 3D Pro) is shown on figure 2. It is worn like ordinary goggles. The resolution of HMD is 800×600 pixels, refresh rate is 60 Hz, and the field of view is 26 degree along the diagonal.

The third display device is Benq PB6100 projector (illustrated in figure 3) with a light output of 1500 ansilumens. At a three-meter distance, it projects a 1340 mm \times 1010 mm image with 1680 mm diagonal on a projective screen. The resolution is 800×600 pixels, refresh rate is 60 Hz, and the field of view is 25.2 degree.



Fig. 3. Projection display Benq PB6100 [9]

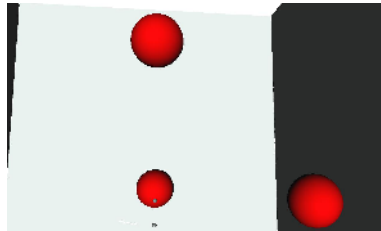


Fig. 4. Experiment environment



Fig. 5. Tracker VR SPACE Wintracker

Experiment environment created by EON professional 5.5 software is a 50cm \times 50cm \times 50cm cube. As shown in figure 4, the cube background is set to a white color, two dark gray tiles are drawn in the vertical plane at the right and left screen. The purpose of the cube is to enhance the perception of depth in our virtual reality

environment. The cursor is shaped into a sphere and motivated by VR SPACE Win-tracker (see figure 5) attached on subjects' base proximal phalange of medius. There were three red sphere targets located respectively in X, Y and Z directions.

2.3 Procedure

A 3×3×3 fully within subjects repeated measures design was used. The factors are three display devices (3D TV, HMD and projection display.), three movement directions (X, Y and Z direction) and three levels of ID (2, 3 and 4 bits). Movement directions Y was into the screen, X was horizontal across the screen and Z was vertical across the screen. IDs were produced by a constant target distance, 19 cm, and three target diameters. The C:D ratio was always 1:1. So, a hand movement in a particular distance resulted in an equal cursor movement.

At the start of each condition, subjects were allowed practice trials to familiarize tasks. Following this, subjects carried out all 27 experimental conditions in a random order to minimize the effect of learning and fatigue. Subjects were instructed to point as fast as possible while still maintaining high accuracy. Movement time started at the start point pressed and did not stop until correctly clicked inside the targets with a mouse grasped in hand. Each condition consisted of ten pointing trials, the average movement time and throughput of these ten pointing was recorded for ANOVA analysis.

After completion of each condition task, subjects were instructed to respond to an SSQ assessment questionnaire asking them to rate their experience of this condition. The questionnaire consisted of ten questions: discomfort, fatigue, boredom, headache, eyestrain, sweating, claustrophobia, disorientation, nausea and difficulty concentrating. Subjects were asked to respond to each question with a rating from low to high and these scores were collected and transferred to the Minitab software for the statistical analysis.

3 Results

3.1 Movement Time

Mean movement time for the three display devices: 3D TV, HMD and projection display respectively were 3689, 4324 and 3467 ms, there were significant differences between display devices in movement time ($F_{2, 234} = 34.31$, $p < 0.01$). The movement time for projection display was the fastest and HMD took the longest time. Further post-hoc Duncan test showed that the movement time of HMD was significantly longer than 3D TV and projection display. The main effect for movement directions ($F_{2, 234} = 35.04$, $p < 0.01$) and IDs ($F_{3, 234} = 190.82$, $p < 0.01$) were also significant in movement time. Movement time were 4323 ms for the highest Y direction, followed by Z direction (3709 ms) then the lowest X direction (3448 ms) and it increased with the level of indices of difficulty (2820 ms for 2 bits, 3075 ms for 3 bits and 4912 ms for 4 bits). Post-hoc Duncan showed that the movement time was different between the three movement directions and between the three levels of IDs statistically. There were significant IDs by display devices and IDs by movement directions interactions on movement time.

3.2 Throughput

Throughput computed for the projection display at 0.9144 bps was the highest. For 3D TV and HMD was 0.8610 and 0.7320 bps individually. The main effect for display devices was clearly significant ($F_{2, 234} = 35.01$, $p < 0.01$). Further Duncan test results showed that there was no significant difference between projection display and 3D TV, but both of them were obviously higher than HMD.

The ANOVA results also revealed significant differences between movement directions ($F_{2, 234} = 46.99$, $p < 0.01$) and IDs ($F_{2, 234} = 9.87$, $p < 0.01$). The post-hoc Duncan test showed that Y direction (0.7135 bps) was statistically lower than X (0.9210 bps) and Z (0.8729 bps) directions. Throughput for three levels of IDs was 0.7799, 0.8523 and 0.8752 bps in order and it increased with the level of ID. The post-hoc test showed that the throughput obtained at 2 bits was statistically lower than it obtained at 3 and 4 bits. There was a significant interaction between IDs and movement directions.

3.3 Simulation Sickness Questionnaire

The means and standard deviations of the responses on the six of ten questions of the SSQ are shown in Table 1. The remaining four questions, sweating, claustrophobia, disorientation, nausea, where participants didn't experience are excluded in this table. The results of the questionnaire analysis showed that all of these six responses are statistically significant between display devices. Subjects rated the discomfort, fatigue, boredom, headache and eyestrain higher scores while using HMD than using 3D TV and projection display obviously. These six questions mean were lowest for the projection display, it implies that subjects considered projection display was a more comfortable and did not induce fatigue, headache and eyestrain. Scores rated in discomfort, fatigue and eyestrain for 3D TV were near the midpoint, it did not induce headache as projection display.

It could be concluded from these questionnaire data that the SSQ assessment showed significant difference between the three display devices. Based on the results, subjects showed preference for projection display.

Table 1. Simulator Sickness Questionnaire rating of three display devices on 5-point scale

Variable	3D TV	HMD	Projection	P-value
Discomfort	2.90(1.02) ^b	4.60(0.54) ^c	1.00(0.00) ^a	0.000
Fatigue	2.89(0.77) ^b	4.44(0.50) ^c	1.08(0.27) ^a	0.000
Boredom	1.84(0.54) ^b	2.26(0.53) ^c	1.02(0.15) ^a	0.000
Headache	1.06(0.23) ^a	3.01(0.44) ^b	1.00(0.00) ^a	0.000
Eyestrain	2.68(0.90) ^b	4.47(1.03) ^c	1.09(0.39) ^a	0.000
Difficulty concentrating	1.99(0.57) ^b	2.79(1.27) ^c	1.09(0.32) ^a	0.000

1. Data are presented as mean (SD).

2. a, b, c groups from the post-hoc Duncan test.

4 Discussion and Conclusion

Based on the result of the study, it seems that the 3D stereo television technology introduced only recently may not provide enough perceptual depth to enhance movement performance of visually-controlled task in a 3D VE as one would have anticipated. The projection display obtained the best performance and preference among the three display devices. The HMD gave the worst result in both the experimental task and the SSQ assessment due to the accompanied discomfort and fatigue. Chun et al. [6] considered that it may be due to its limited configuration where the resolution is only 800×600 pixels with a small field of view. In all conditions, movement time increased linearly with levels of IDs. This is in line with previous studies that Fitts' Law was applicable to the performance evaluation of interaction with display devices. In addition, the predictive models developed by this study are reported as a reference for predicting interaction performance in the 3D virtual reality environment.

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