Investigating Visual Dominance with a Virtual Driving Task

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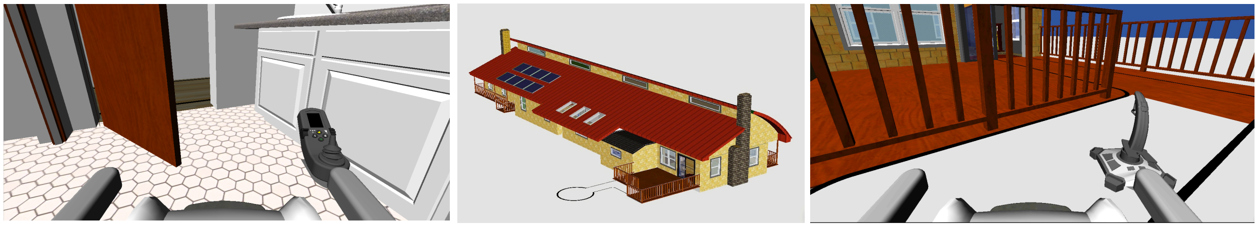

Figure 1: Power wheelchair simulator: power wheelchair joystick (left), gaming joystick (right), and house environment (center)

Abstract

Most interactive input devices for virtual reality-based simulators are proprietary and expensive. Can they be substituted with standard, inexpensive devices if the virtual representation of the input device looks and acts like the original? Visual dominance theory would appear to support such a possibility. According to this view the visual aspects of the displayed input device within the virtual environment should override the haptic aspects of the real device. We tested this visual dominance theory in a VR power wheelchair simulator scenario comparing standard gaming and proprietary wheelchair joysticks in combinations with their virtual counterparts and measured the effects on driving performance and reported experience. In a study with 48 participants we found significant support for visual dominance effects on driving performance. At the same time, users reported awareness of the presence and change of real joysticks and virtual representations.

Keywords: Virtual reality, joystick, Power Wheelchair (PWC) simulator, interaction, simulation, visual dominance theory.

Index Terms: H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities

1 Introduction

PWCs are expensive and driving one requires training and assessment, which is a costly procedure. This has captured the attention of researchers who see the use of a virtual environment as a potential training and assessment tool. In this study, we asked the fundamental question of how much can and should be simulated and what parts or components have to be real/physical. Ideally, everything would be virtualized – this being (a) the most cost effective, because there is no need for a wheelchair or wheelchair parts, and (b) it would allow for the highest degree of control of most parameters of the PWC driving experience.

Of particular interest is the provision and simulation of the input device, in our case a joystick. Is it necessary to use the expensive and proprietary joystick with which PWCs are equipped, or can we use a standard, inexpensive PC gaming joystick instead, if the virtual representation of the input device looks and acts like the original?

Visual dominance theory supports this possibility - the virtual representation would override the haptic experience of operating the real joystick. Two aspects of virtual reality (VR) simulations have to be considered: (1) the actual joystick, physically operated by the user, and (2) the virtual representation of the joystick within the virtual environment. Perhaps the virtual representation of a real PWC joystick might be functionally equivalent to the original. In this study we investigated whether this was true for our PWC simulation. Our contribution lies in the demonstration of the dominance of the visual over the tactile experience of input devices in virtual reality systems, exemplified by our joystick-operated, power wheelchair-driving task.

2 Visual Dominance

In recent years, a number of investigators have focused their attention on sensory dominance and the conflicting information of two different senses. In many experimental situations, psychophysical research in the past has shown evidence that vision is so powerful that it tends to override other sensory information. One of the earliest studies was by Rock and Victor in 1964. They were able to demonstrate visual dominance in judgments of size [1]. Subjects were asked to grasp a square from beneath a piece of cloth and view it through a minifying lens. They were required to give their impression by either matching it to another object, or drawing it. The researchers concluded that visual impressions completely dominated.

A study by Srinivasan et al. [2] performed a series of psychophysical experiments investigating the impact of visual appearance on human perception of the discrimination stiffness of virtual springs in a virtual environment. They found that vision could mislead subjects during differentiation between two springs. While subjects pressed the springs, they also visually observed the displacement of the springs on a computer monitor. The result shows clearly that vision is dominant over the kinaesthetic sense.

Similar research was conducted by Lecuyer et al. [3] to determine whether a passive isometric input device, along with visual feedback, could provide "pseudo-haptic feedback" to the subject. Their aim was to use visual dominance to influence a subject's perception of the displacement of the virtual spring. The final result indicates that subjects' perception was blurred by the visual information that gave them the sense of using a non-isometric device.

Our study is designed to investigate the visual dominance theory in a VR power wheelchair simulator scenario and measures its effects on driving performance and reported experience.

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3 User Study

The goal of this study is to test visual dominance theory in a VR power wheelchair simulator scenario, and compare standard gaming and proprietary wheelchair joysticks in combinations with their virtual counterparts, and measure their impacts.

In order to evaluate physical joysticks, we used a gaming joystick (Attack3) and a PWC joystick (Q-Logic control). However, the PWC joystick had to be modified for use with USB input. Therefore, an Arduino-based LeoStick board was electronically connected, programmed, and calibrated to read the PWC joystick outputs. The outputs were also mapped to be similar to the gaming joystick. Both joysticks were placed on a wooden frame (Figure 2). We used a 17" Alienware laptop to run the simulator, resolution 1,920 x 1,080. Google SketchUp was used to design the 3D models and Unity3D was used as the graphic engine platform for the simulation. Similar to a real PWC, pushing the joystick further in any direction increases the speed of the virtual PWC and rotates the PWC in the direction pushed. Joystick lever/handle movements were also virtualized to correspond to the user's joystick movements. Realistic designs for both the gaming joystick and the PWC joystick were modelled in order to be represented in the VE.

Figure 2: Experiment setup

A total of 48 participants (aged 17 and above) took part in a 2x2 factorial design. We evaluated two within-subjects conditions: the physical joystick handled by the participant (Gaming or PWC joystick) and the virtual joystick represented on the screen (Gaming or PWC joystick). We use a domestic environment (house) for the simulation. The environment was built to meet the Americans With Disabilities Act (ADA) standards for accessible design. The task was to drive as quickly and accurately as possible through an indoor environment by following an ideal path (two black lines). Directions, yellow arrows on the floor, were displayed as necessary. The user task represented all possible movements that a PWC user would make.

In a within-subject experiment design, each participant repeated the same task four times. To balance ordering effects, first, subjects were randomized in counterbalanced order. Second, subjects were unaware of the repetition. The task (path following) together with the indoor environment was mirrored so that once participants reached the end they had already done the task twice. The other two conditions were simply driving backwards through the same path they had just finished. This minimized the learning effect because 1) subjects were unaware of the repetition, 2) subjects did not expect what was coming next, and 3) even if they were aware of the repetition, it was hard to know which direction to travel next as the right turn became left when driving in the reverse direction. Two metrics were measured: objective metrics (user driving performance) and subjective metrics (users' perception)

To measure users' driving performance, the following objective metrics were recorded: completion time, path boundary violations, and wall collisions. The overall performance score was calculated from the number of path boundary violations (pathViolations), the number of wall collisions (wallCollisions) and the total time in seconds (totalTime) required for the completion of the task.

To measure user experience, we developed four questions consisting of seven-point Likert-like scale items. All four questions were asked once after completion of all conditions. The four questions were as follows: 1) Overall, I felt as though I was operating the virtual joystick presented on the screen, 2) Overall, I felt as though I was operating the physical joystick in my hand, 3) Overall, I was aware of the switching between the virtual joysticks, and 4) Overall, I was aware of the differences between the joystick on the screen and the one in my hand.

The experiment was run during a local science festival where participants came to participate in a wide range of scientific activities. Upon arrival participants were welcomed and introduced to the system and experiment. Participant consent was obtained electronically by clicking 'YES' if they wanted to be part of the experiment. Participants were informed about the type of the virtual PWC (mid-wheel) and how it moves. Switching between virtual joysticks was done automatically through the simulator depending on the condition order set. When a stop sign appeared on the screen, participants were asked to switch between the physical joysticks. The stop sign appeared according to the condition order as well.

We found that the propriety, expensive, original power wheelchair joystick can be substituted with an off-the-shelf, inexpensive, gaming joystick if there is an appropriate virtual representation of a PWC joystick. The displayed input device within the virtual environment overrides the haptic aspects of the real device. The results show statistically significant support for visual dominance effects on users' driving performance, measured in path and wall collisions. It was also interesting to see that subjects reported being aware of the switching between virtual joysticks and were also aware of the joysticks displayed and in their hands, but despite this their performance was still strongly affected by the visual dominance.

Our findings offer guidance on which VR input devices are necessary and appropriate and which virtual device representations can and should be implemented for power wheelchair simulators. More cost effective systems can be built, because implementing a virtual joystick representation is much cheaper than using and modifying a proprietary PWC joystick. The findings of this research could be generalized towards other vehicle simulation systems, in particular towards navigational interaction in VR systems in general.

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