A HMD BASED VIRTUAL REALITY DRIVING SIMULATOR

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Summary: Recent advances in optics, HMD design, 3D graphics chips, and processes for personal computers have combined to make HMD based virtual reality driving simulators available at low cost. A HMD with a resolution of 1,024 by 768 with a FOV of 50^{o} diagonally is now available for about $20,000. A graphics processor that can render large databases at fast frame rates costs only $400. Personal computers can now support multiple processors that run over 1 Gigahertz. We discuss visual concerns with a HMD, choosing a HMD for a driving simulator, HMDs compared with fixed displays, consequences of improved frame rates, autonomous vehicles, and the use of a HMD based driving simulator for studying drivers who have cognitive impairments.

INTRODUCTION

One of the first driving simulators to use a helmet-mounted display (HMD) was developed by Levine and Mourant (1995). At that time the technology was limited due to 1) the low-resolution of the HMD, 2) the excessive weight of the HMD, and 3) long rendering times for the 3D graphics environment. The low resolution of the HMD resulted in boxy buildings and vehicles. Road signs could not be detected and read at normal distances. The excessive weight of the HMD produced strain in drivers' neck and shoulder muscles after a short time period. Subjects were almost always aware that they were in a virtual environment because of the poor quality visual presentation and an uncomfortable feeling from wearing the HMD. Long scene rendering times meant low frame rates which did not permit the sensing of realistic movement in a three-dimensional environment.

Visual Concerns Associated with HMD Displays

A common problem associated with HMD use has been eyestrain (Costello and Howarth, 1996; Mourant and Thattacherry, 2000). Mourant and Thattacherry studied HMD use while driving in a virtual environment and found that oculomotor discomfort increased significantly for both males and females after a 20 minute test run.

Peli (1998) has reported that the effects of using an HMD may contribute to: (1) simulator sickness resulting from vestibular-visual conflicts, (2) accommodative difficulty presumed to be associated with instrument myopia, (3) binocular function difficulties due to a mismatch between the device and the individual user's visual system [e.g. different inter-pupillary distances (IPDs)] and (4) binocular (and possibly accommodative) difficulties associated with the de-coupling of the natural relationship between accommodation and convergence in stereo binocular HMDs employing image disparity. When comparing a HMD use with a desk-top computer display, Peli found no differences in accommodative difficulty and binocular function.

Choosing a HMD for a Driving Simulator

The driving task depends on the acquisition of high quality visual information. If virtual environment driving simulators are going to provide a similar experience to real-world driving, then the process of gathering visual information in the simulator and the real-world needs to follow the same patterns.

An important factor to consider in a HMD is field of view. Table 1 below compares two HMDs that we have used in the Virtual Environments Laboratory at Northeastern University and one that recently been introduced.

Table 1
Partial Specifications of HMDs

	Kaiser XL 50	**Virtual Research V8**	**IReality CE-500**
Resolution	1024 x 768	640 x 480	800 x 600
FOV	50^o diagonal	60^o diagonal	30^o diagonal
IPD	55-75 mm	52-74 mm	?
Weight	29 ounces	ounces (light)	?
Cost	$20,000	$8,000	$2,700

Traditionally users of HMDs have been faced with a resolution FOV tradeoff. Low FOVs have been associated with high display resolutions. As seen above this no longer is the case. The Kaiser XL-50 offers both high resolution and a fairly large FOV. Note, however that the price might be considered expensive. Since when driving, a large FOV and high resolution are both highly desirable, the choice is clear if money does not matter. The high price of the Kaiser XL 50 is due to the lenses. It is technically difficult to manufacture high-resolution lenses that have a fairly large FOV.

There is some question about the validity of the acquisition of driving information when using a HMD with a small FOV. In particular, when driving on curvy roads and/or making left/right turns, a driver would be forced to make large and perhaps many head turns in order acquire information to use for vehicle control using a HMD with a small FOV. Mourant and Rockwell (1972) have suggested that experienced drivers make good use of peripheral vision. A HMD with a small FOV would not allow the use of such peripheral vision. Pictures of the three HMDs in Table 1 are shown below in Figure 1.

Figure 1. The Kaiser XL 50, VR 800 and CE-500 HMDs.

Ergonomics Associated With HMDs

Both the weight and the comfort of a HMD affect a driver's performance when using it. From our experience the weight of the XL 50 is considerably less than that of the VR-800. Less weight on their heads, means drivers experience less fatigue in neck and shoulder muscles, and are also able to make head turns in a more natural manner. The comfort of a HMD is related to how well it "fits" a driver's head. We have used the VR-800 with about 80 drivers and the XL-50 with only a few. It appears that the XL-50 is considerably better than the VR-800 in terms of comfort.

HMDs Compared With Fixed Displays

When compared with the use of fixed displays (wide screen or multiple monitors) HMDs have several advantages. First, their footprint is considerable smaller. A "driver" simply needs a steering wheel and brake/gas pedals when using a HMD. Thus, if HMD simulators were used in driver training or for licensing examinations, an installation would require less space. Second, when the HMD is accompanied by head tracking, a driver can experience a 360 degree view (about 50 degrees at a time). This makes it possible to realistically experience lane changing, merging, and parallel parking maneuvers. Such maneuvers can be difficult to realistically simulate with a fixed display. Third, when using a HMD, a driver can only see and hear the virtual 3D environment, and not irrelevant stimuli in the room where the simulator resides. Thus when using a HMD rather than a wide screen simulator, drivers are more likely to experience a sense of presence and believe they are in an actual real-world driving situation.

FACTORS AFFECTED BY FRAME RATE

Consequences of Improved Frame Rates

The improvements associated with displaying 3D graphics on personal computers in recent years have been astounding. Quality textured scenes with moderate sized databases can now be rendered on personal computers at frame rates in access of 50 fps. A graphics card that enables this is VisionTek's GeForce 3 Graphics Accelerator, which uses Nividia's GeForce3. It has fill rates of up to one billion pixels per second and processes more than 31 million sustained triangles per second.

In a driving simulator fast frame rates are desirable in order for the user to experience seeing realistic vehicle movements with respect to turns and acceleration/deacceleration.

Fast frame rates may mean that we now have excess capacity that can be used to render the vehicle's rear-view and side-view mirrors as part of the visual scene. This is done by having additional "cameras" positioned properly and directed to the rear scene, doing a left-right reversal and properly placing the images representing the mirrors on the forward scene.

Autonomous Vehicles

Fast frame rates are also needed to display other traffic in the form of autonomous vehicles. Recently, considerable progress has been made in the modeling of autonomous vehicles that represent different drivers who appear to be driving when drunk or aggressively. Al-Shihabi and Mourant (2001) have used AI techniques to make autonomous vehicles behavior in ways similar to actual older, drunk, and aggressive drivers.

USE OF A HMD BASED DRIVING SIMULATOR

Now that it is possible to provide a realistic driving experience using a HMD based virtual reality driving simulator, we will soon begin using the simulator to evaluate cognitively impaired drivers. Some advantages of using VR-based driving simulators for evaluation purposes are given below.

1. The performance of the participant driving the simulator may be easily measured in a virtual environment since the position, velocity, acceleration, and heading of the driver's vehicle is known at all times. The simulator can compute and display, in real time, a driver's longitudinal and lateral control performance.

2. The type and amount of testing may be tailored to the individual. More measurements may be taken using scenarios where a driver's performance is poor.

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