Exploring the suitability of virtual reality for driving simulation

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Abstract - Head mounted displays (HMDs) is an emerging technology and the availability of affordable systems is growing fast. Replacing projector and large screen solutions with head mounted displays may appear as an appealing solution. However, inherent properties and technical limitations of these systems need to be understood and considered before making the leap to virtual reality.

This paper outlines some of the most fundamental limitations of head mounted displays relevant to this context, both from a technical and human factors perspective. Desirable properties of scenarios and types of studies are deduced, based on these limitations. Finally, a meta analysis is performed on the feasibility of transferring simulator studies found in the literature to platforms with head mounted displays.

The results suggest that a noticeable amount (40%) of the investigated simulator studies could likely have been performed with head mounted displays. This number could be increased further with technical advances in display resolution, display technology, reduction in latency, etc.

Keywords: Virtual Reality, Head Mounted Display, Driving Simulation

Introduction

Previous usage of virtual reality in the automotive context has mostly concerned engineering design, vehicle ergonomics, styling, interior lighting, and perceived quality [Kem14]. Meanwhile, driving simulators using projectors or large display systems have been tasked with driver training and most of the studies relating to human factors.

As virtual reality technology has become more and more ubiquitous, the interest for using head mounted displays (HMD) in driving simulators have surged. However, one cannot simply replace the traditional displays with a virtual reality solution without considering the potential effects that it may have on the results. Virtual reality technology comes with its own set of limitations and drawbacks that need to be considered before moving away from traditional display solutions. In addition there are setups where HMDs are used while driving real vehicles, which requires significant understanding of the technology.

The selected studies from the driving simulation community have been supplemented with generalized studies from the virtual reality community, which have explored human factors in virtual reality in a more broad sense.

Benefits of HMDs

Using HMDs instead of projectors or other large display systems have the additional benefit of being more compact and the hardware cost is lower. The installation is also much simpler compared to multi-projector systems.

HMDs used to be exotic hardware which required large investments and technological skill to use. With the new wave of HMDs targeted towards home users the investment cost has dropped radically, but to use an HMD still require technological skill to avoid common pitfalls.

Binocular depth cues

Most HMDs uses binocular imaging, i.e. two different images for the left and right eye. Binocular imaging give strong depth cues, especially up close. The effect diminishes with distance with an upper limit of about 40 meters [Bad14].

Stereo projectors can present binocular imaging as well, either by using active shutter glasses or glasses with polarizing filters or band-pass filters. Regrettably, there is usually some light leakage leading to crosstalk [Woo12], i.e. some of the image intended for one eye get displayed to the other eye as well. This can in turn reduce the perceived image quality and the sense of presence.
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Presence

Since the user of an HMD is completely surrounded in the virtual environment the level of presence is increased. Improved presence suggests that the user behavior would be more similar to real world action, compared to other display solutions were presence is rated lower [Bow07].

Completely virtual environment

One major benefit of immersing the user in a virtual environment is the ability to change every part of the environment as desired. This makes studies involving different interior designs effortless compared to changing the real physical environment in the vehicle.

Challenges of HMDs

Virtual reality technology is not without challenges. Some of the most fundamental limitations in the context of driving simulation are listed below.

Resolution & Field of view

The current generation of HMDs uses displays and lenses capable of an angular resolution of 10-15 pixels per degree. In comparison, projector based simulators usually have an angular resolution of 30-40 pixels per degree. The low resolution of an HMD can make objects hard to discern at distances were they would be clearly identified in real life. It could also reduce the legibility of road signs and other important information, both inside and outside of the vehicle.

According to the Commission Directive 2009/112/EC any applicant applying for or renewing a driving license need to the minimum binocular visual acuity, with corrective lenses if necessary, of at least 0.5 when using both eyes together. This visual acuity corresponds roughly to 30 pixels per degree, which makes the current generation of HMDs fall well below the limit where you are deemed fit to drive.

The horizontal field of view of most current generation HMDs are between 90-100 degrees. A healthy individual have a horizontal field of view of about 200 degrees. This makes any task where the user is going to detect objects in the peripheral hard to perform when using an HMD. The Commission Directive 2009/112/EC states a lower limit of 120 degrees horizontal field of view to be considered fit to drive.

Lenses

The lenses used in the HMD can either be conventional lenses or Fresnel lenses. Fresnel lenses can achieve the same focal length as conventional lenses by dividing the lens into concentric rounded sections. Since each section is moved down Fresnel lenses require considerably less mass and can be made thinner than conventional lenses. The drawback with Fresnel lenses is that they can produce optical artifacts known as Fresnel rings. Depending on the density of the sections these rings can be seen as either distinct rings or as bright haze. The effect is particularly visible when displaying bright objects on a dark background. It is therefore not advisable to use HMDs which employs Fresnel lenses when performing dark scenarios, such as night time driving.

Latency

Latency is the time delay from the input to output in a system. Low latency in virtual reality has been proven to be important for cognitive functions such as sense of presence, spatial cognition, and awareness [Mee03, Pap12]. When latency increases, the user experiences decreased visual acuity, decreased performance, decreased presence and is less susceptible to training [All01]. Increased latency is also associated with increased levels of simulator sickness [Buk12] and stress [Man04].

Accommodation-Vergence Conflict

HMDs use binocular imaging but the convergence distance is fixed. This means that even though your eyes are presented with images of objects that are supposed to be at different distances, your eyes are still converging at the same angle to keep the image in focus. Since convergence is one of the cues that the brain uses to infer distance this results in a sensory conflict. This can lead to eye strain, blurred vision, and headaches [Shi11]. There are examples of early research prototypes of optical systems which use varifocal or multifocal displays to eliminate this effect [Mat17]. But until these types of systems are generally available it is advisable to try to minimize the necessity of shifting focal distance when using a fixed focal HMD.

Tracking inside full motion simulators

The most common tracking technology to track the position of the HMD is to use inertial tracking [Bli16a]. However if inertial tracking sensors is used inside a full motion driving simulator these sensors will pick up the accelerations from the movement of the user inside in the vehicle as well as the accelerations from the motion system as well. This problem can in theory be solved by subtracting the inertial information from the motion system [Fox00]. In practice this entails bypassing the tracking algorithms developed by the HMD vendor, thus often also bypassing some of the low level latency combating techniques placed there by the vendor.

Simulator Sickness

There are multiple theories why motion sickness occurs inside virtual reality; sensory conflict theory [Rea75], evolutionary theory [Tre77], postural instability theory [Ric91], rest frame hypothesis [Pro03], and eye movement theory [Ebe94].

There are individual factors which affect the susceptibility for motion sickness such as health status, previous experiences, gender, age, and the users own expectations [Jer16]. There are also hardware factors which may contribute to motion sickness in virtual reality, i.e. latency, tracking errors, wide field of view, low refresh rate, flicker, accommodation-vergence conflicts, as well as the weight and fit of the HMD. Using a motion system may help alleviate simulator...
sickness, but only if done well otherwise it may have the opposite effect.

The most common way to measure motion sickness is via the Kennedy Simulator Sickness Questionnaire (SSQ) [Ken93], where the users are asked to rate 16 different common symptoms on a 4-point scale. The trouble with this questionnaire is that it is hard to quickly administer during a test. Another option is to use the Fast Motion Sickness Score [Kes11], where the user is asked to rate their level of motion sickness once per minute.

A recent study comparing the influence of non-VR (2D, stereoscopic 3D) and VR (HMD) was performed in a fixed base simulator [Wei17]. The study focused on lane change maneuvers. The results showed no significant difference in neither driving performance nor physiological responses, although reported significant increase in simulator sickness for the HMD-condition.

**Completely virtual environment**

One major drawback of having a completely virtual world is that you no longer can see your own body. Especially problematic is the fact that you no longer see your own hands and fingers. Tracking of hands and fingers can be done and re-introduced in the virtual world. This can be done either by attaching tracking equipment to the hands or by contact free tracking using image based systems.

Another drawback of having a completely virtual world is the lack of haptic feedback from the virtual interior. Solutions may include replicating the interior shape and adding real buttons and knobs to give the user the correct haptic feedback. Although this counteracts the one greatest benefit of having the full virtual environment to begin with, i.e. cost and ease of adaptation.

**Review of simulator studies**

To evaluate the potential transferability of driving simulation studies to virtual reality and HMDs, we reviewed all the papers published during the last five years from the two largest conferences within the simulator community. A total of 734 papers were reviewed. 203 of these papers concerned interactive driving simulation studies where a test subject was either driving or riding along in a simulated vehicle.

The studies were categorized into different factors:

**Driving behavior** – This included what types of driving maneuvers the subject was expected to perform and how this might affect their head turning behavior. The required lateral motion was split into three levels low, medium and high. Studies that featured low level lateral motion was typically studies which included driving on a highway without any quick side maneuvers. Studies were the subject drove on a rural road or similar were categorized as medium level, while lane change maneuvers or intense city driving were categorized as high level.

Head turns were categories in a similar fashion. Studies performed driving on a highway without traffic or where simulators with a single display in front of the driver was used was categorized as the lowest level.

Driving on a highway or rural road with low traffic density was categorized as medium level and driving in dense traffic or complicated city environments were categorized as high level.

**Motion sickness** – If the study listed how many of the subjects that were affected by motion sickness and if so, which type of method that was used to measure it. The most common case was that reporting of rate of motion sickness was omitted, which accounted for 148 of all published studies. 15 papers reported detailed motion sickness ratings using SSQ, FMS or similar rating systems. 3 papers simply reports that all the subjects suffered from motion sickness in some form. The rest of the papers only published how many of the subjects that suffered motion sickness at all.

**Interactivity with hardware** – If the experiment conditions required subjects to interact with hardware inside the cabin such as buttons or knob in the instrument cluster or other third party hardware.

**Virtual reality studies**

We found ten papers which already used HMDs. Five of these studies where technology evaluations where the technical details of virtual reality was explored. Two of these concerned a bicycle simulator [Suz15, Suz17], while the other three concerned driving a real car while wearing an HMD either sitting inside the car [Jeu12, Bl16b] or remote driving [Ric15].

Of the remaining five papers, two were exploring simulator sickness [Ayk14, Col16] and one concerned how to interact with tangible interfaces while using virtual reality [Las17]. The final two papers were more traditional user studies; one study regarding detection of motorcyclist by car drivers [Boe17] and one study were pedestrians used a smartphone at street crossings [Sob17].

**Transferable scenarios**

Scenarios that would be feasible to transfer into virtual reality without special considerations are scenarios with low lateral motion and few head turns. The scenario should also preferably not require the subject to interact with any hardware inside the cabin. Although the best candidates would be the scenarios where the low lateral motion, few head turns and no interior interaction is required. Calculating the intersection of segmented data gives us 84 (41%) potential candidates studies which probably could be moved into a simulation environment where an HMD is employed as display.

**Conclusion**

Although most of the driving simulation studies are still performed using simulators equipped with projectors or large displays, it is possible to use HMD systems instead. One does need to be mindful of the current drawbacks of the technology and design the simulation scenarios accordingly. This study suggests that despite the current limitation of the HMDs, as many as 40% of the reviewed studies could have been performed using an HMD.
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