A comparative study of using Augmented Reality interfaces for vehicle navigation

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Abstract

Augmented Reality (AR) is technology that provides a view of real world environment with which has augmented or virtual components. In this thesis I explore how AR can be used for in-vehicle applications. AR systems can be used for navigation applications, combining this with capabilities like monitoring of data relevant to the driver could be a powerful tool for in vehicle assistance in automobiles. Some research is being done on using AR in automobiles for in-vehicle assistance using different technologies like see-through head mounted displays (HMD) or using projectors to use the windshield as a see through, heads up display (HUD).

With all the research being done on AR display technologies in vehicles, a concern that arises is the possibility of the AR components distracting the driver from their normal driving activities. Less research has been done on comparing between different AR display types.

For my master thesis, I investigated the effectiveness of three technologies to show AR content:

- using an HMD similar to Google Glass
- using the Windshield as a display
- using a dashboard mounted console

Based on the results of the study, it was found that the Windshield based AR HUD was superior over the fixed console based HDD (AR Lens) and the Head Mounted Display. The Windshield Display performed superior to the other displays in terms of ratio of number of navigational errors, maintaining the speed limit and ability to detect objects in the surrounding. It was also preferred by the subjects over the other displays. The AR Lens performed relatively average in the test study and performed higher than the HMD for most of the tests. The HMD showed comparatively better results than the AR Lens in maintaining the speed limit but was the least preferred by most of the participants.

Contents

Listing of figures

List of Tables

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1 Introduction

THIS THESIS AIMS AT comparing different Augmented Reality (AR) Displays for vehicle navigation. AR technology is usually considered to be a live view of the real world, onto which extra data is layered or superimposed and can be interacted with[32]. AR can be applied in many application domains and could have a wide scope in the automobile industry where it could improve the driver's user experience by superimposing information that would supplement the user's understanding of his physical surroundings.

AR systems can provide an intuitive depiction of information because real world objects can coexist with virtual objects and works in real time [21]. The user is able to access much more information than they normally can using their senses, these help them understand the real world better[21]. There are many applications of AR in navigation. For example virtual arrows can be overlaid on the road. In particular, there are many research systems that prove the applicability of AR in automobiles[20, 22]. On one hand providing all this extra information to the driver is useful as it helps them recognize objects easier and faster, and decreases their reaction time[40], but it also brings about the risk of overwhelming the driver with too much information and of proving to be too much of a distraction[38, 43].

Most of the existing research in using AR for in-car navigation compares presenting information on Heads Up Displays (HUDs) with traditional Head Down Displays (HDDs). For example, comparing projecting virtual information on the windshield display of the car with information shown on an in-car screen[23, 34]. There are also some interface research papers comparing the advantages of using AR instead of traditional map navigation. However, there is less work done on studying on how AR can affect drivers when placed on different displays. In this thesis, I will be comparing AR on Head mounted displays (HMD), HUDs and HDDs using both qualitative and quantitative evaluation methods.

There are several ways in which an AR system HUD can represent data to a driver in a car. The most studied method currently is to project vital information like directions, speed and warnings onto the windscreen in the driver's line of sight to reduce the time the driver has his eyes off the road[42]. The advantages of overlaying elements on the windshield is that it offers a large field of view and does not require any kind of user head tracking, although you may need to track the car position and orientation to overlay the correct virtual information on the real world. However, there are a few challenges for developing fixed HUDs that overlay augmented elements on the windshield, such as the level of visibility in direct sunlight and the obstruction of real world elements due to augmented overlays.

Another way to display augmented virtual elements is through Head Mounted Displays (HMDs). HMDs are display devices worn on the head that show projected data. They have optics that are close to the eye, which create a virtual display overlaying the real world and can provide an immersive experience for the user. In order to align virtual images with the real world, HMDs require some head-tracking algorithms to track the movement and direction of user's viewpoint. Initially HMDs had the disadvantage of being too heavy and uncomfortable, but since the release of the lightweight displays such as Google Glass[8], this limitation has been minimized. Another disadvantage of HMDs is that they are not very immersive and their graphics are sometimes not bright enough to be seen clearly in bright sunlight.

The most common display used to represent AR elements for navigation is by using a console mounted on the dashboard. This console shows AR elements on a view of the real world (obtained through a camera showing the view from the car). This technology was first commonly used to provide assistance for parallel parking by using AR imagery with reverse cameras. The main advantage of using a dashboard mounted Head Down Display (HDD) is that the AR information will not clutter the driver's view of the real world; However the driver does need to take their eyes off the road to view the display, so this is also the prime disadvantage of the display.

This thesis focuses primarily on comparing different displays for representing AR information for vehicle navigation. It will compare between using the windshield as an AR display, using a Head Mounted Display similar to Google Glass, and a fixed console based 'AR Lens'.This is one of the first times that a direct comparison has been made between using these three display technologies for AR navigation.

Testing of AR Technology in real world conditions is a challenge due to safety conditions, which hinders research on using AR for navigation. Most of the testing generally done is through a driving simulator using multiple/projected displays or by driving in the real world under controlled conditions. In this thesis we will use a driving simulator, and in order to test each case as closely as possible

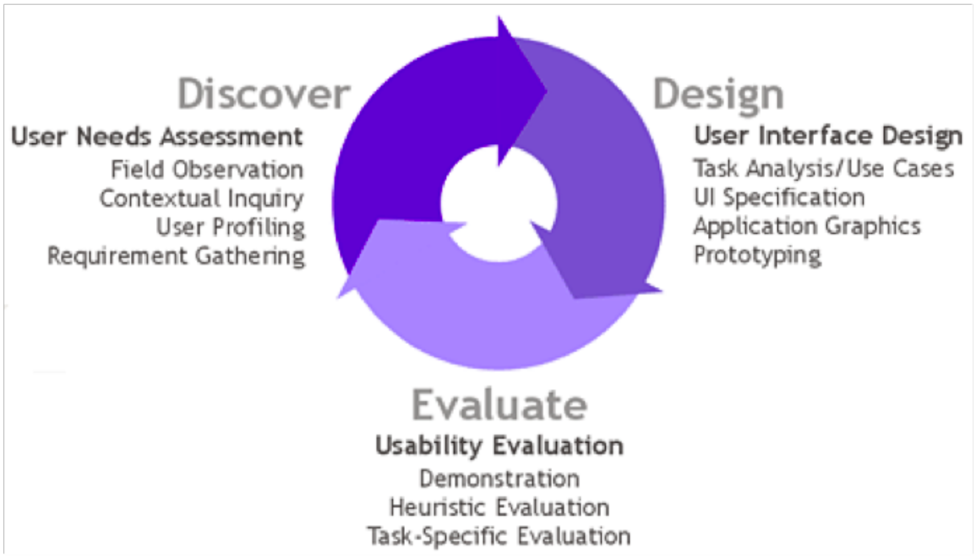

Figure 1.0.1: HCI Design Cycle

to real scenarios, the tests implemented for this research will aim to be as immersive as possible.

To study the comparison of navigation using AR on HMDs, HUDs and HDDs, an iterative design approach was used (HCI Design Cycle) [Fig. 1.0.1]. The first step involves the Discovery Phase, where a needs analysis is conducted to identify user requirements and potential problems. Solutions to these problems are then planned and designed in the planning phase. Then, based on data from the planning phase, solutions are created in the form of low fidelity and in latter stages high fidelity prototypes. These developed solutions are then evaluated, making up for the last stage of the Design Cycle (Evaluation Phase).The design cycle can be iterated around for as many times as needed until the current prototype meets the user needs.

This thesis is split into several chapters. This is based on the structure of the Design Cycle: Discovery, Design, Prototyping and Development, and Evaluation.

The *Related Research* chapter explains the various research done in the fields of HMDs, HUDs and HDDs, and AR and how it has been used for navigation in automobiles. There is also a section in the chapter explaining the additional work done by Dr. Mark Billinghurst, Dr. Gun Lee and I, along with some other members of the HITLabNZ with regard to using AR for assistance in navigation and working of heavy vehicles like excavators. The findings from this work serves as a good base for the research of this thesis, and the chapter ends with an explanation of the research opportunities and how this thesis addresses some of them.

The *Design* chapter explains the various steps taken during the design phase of the HCI Design Cycle like Brainstorming, Wireframing and Use Cases. This lays the base for the development and prototyping chapter.

The *Development and Prototyping* chapter explains the development part of the Design Phase. It explains the various hardware used for the development and the software designed along with the algorithm and flow charts showing the working. It also provides an overall summary of the prototype.

The *Evaluation* chapter explains the user studies conducted in order to evaluate the design of the prototype. It also explains the overview of the design of the study, the hypothesis to be tested and the procedure of the user tests conducted. This chapter is closely linked to the *Discussion* chapter that explains the results and the conclusions drawn from the various data collected from the user tests. The evaluation phase in the design cycle is split into these two chapters.

The final chapter in this dissertation is the *Limitations and Future Work*. It explains the limitations of the study, with suggestions for future work that can be done.

The major contributions of this thesis are:

- A summary of the current research work done in the field of vehicle navigation using AR in HMDs, HUDs and HDDs.
- The creation of a realistic and immersive simulation of each AR Display.

- One of the first studies compare the effect of each of these AR Displays on driving.

2

Related Research

As mentioned earlier, this thesis aims to compare between three different types of AR displays for vehicle navigation. This chapter reviews some previous related research, divided into several sections. The first few sections review the research in each AR display type and how it has been used for navigation. There is also a section that talks about the different evaluation methods used to test the technology and the research behind them. The final section explains the gap in research and how this thesis aims at addressing it..

2.1 AR in Automobile Applications

Safety is an important aspect for drivers, so passive safety features like air-bags, seat belts, and neck supports have been available for a long time. Recently, active safety systems were implemented by using AR in order to reduce the mental load on a driver while they follow directions for navigation and help them concentrate on the road.

One of the biggest problems for a driver is divided attention and their. ability to focus simultaneously on multiple tasks [45]. The problem with navigating while looking at traditional navigational solutions is that the driver's attention is divided between looking inside the car and following the navigation directions, and looking outside the car and driving. This causes the mental load on drivers to increase. One way to solve this problem is to decrease the cognitive distance between their tasks, so that the user feels they are doing one single task rather than separate ones [31]. Sun Y et al [43] studied the effect of commingled division of our visual attention. They studies involved having a user perform a primary task and a secondary task was introduced randomly. Their studies showed that *"attention would be allocated competitively and simultaneously, implying that the secondary task might hijack resources that could have been allocated to the primary task"*[43]. Their studies say that there would be a competition between normal processing when the user is attending to the road and with identifying AR-HUD instructions. This effect is more likely to be prominent when the driving environment is heavily demanding.
One way to reduce visual commingled effects is to use auditory aids [33], but this can be drowned out by ambient noise. AR can be used to complement the driver's view of the physical view of the real world by adding augmented information on top of the physical world, and so reduce divided attention. However, during the design of AR Displays, especially HUDs and HMDs, care should be taken so that it is the easy to identify and follow the information shown, so that it would not affect the primary task of driving.

Use of AR in the automotive industries goes back all the way to the 1990s. Regenbrecht presented an AR Training System for driver safety among other ten different projects using AR in industrial applications [39]
One of the earliest widespread use of AR in the car for navigation was through

Figure 2.1.1: Parking assist using AR Technology on the Ford Fiesta
Credits: Ford Fiesta 2011 Brochure [6]

the use of reverse cameras that assisted in parallel parking . These cameras provided a live stream from the cameras on the rear bumper. The video from the camera had augmented elements that informed the user of the backing space available for the vehicle. Ford Fiesta implemented this in their 2011 models with forward and reverse parking assistance [6] [Fig 2.1.1].

The University of Minnesota's Intelligent Transportation Systems (ITS) Institute used a driver assistance system based on AR technology, and an optical HUD for collision avoidance [41]. The system had a front bumper attached Light Detection and Ranging (LIDAR) to detect vehicles that were nearby and uses the bus-only shoulders . These vehicles were then highlighted using rectangular outlines with different colours demonstrating different positions. It also showed lane markings to assist the driver during difficult traffic conditions. The IV Lab, MVTA, and Schmitty and Sons Transportation are set to release 10 buses equipped with the technology between Minneapolis and Apple Valley, Minnesota, which would operate as a revenue generating service.

Medenica et al. [35] compared emerging navigational aids and their impact on driving. Using driving simulators, they found that using AR Technology exhibits the least negative impact on the driver performance when compared to street view technology.

Pioneer's Cyber Navi[2] used a display that flips down into the drivers field of view. This is similar to the sun visor. It shows essential information to the driver like navigational aids, speed and safety information.

Land Rover and Virgin Galactic also unveiled the Discovery Vision Concept vehicle which features an AR system that gives the driver a "see-through" effect of the terrain ahead by using virtual optical see bonnets [11] and AR elements projected on them.

AR Displays are mainly classified into Heads Up Displays (HUDs), Head Mounted Displays (HMDs) and Heads Down Displays (HDDs).

2.1.1 HUD using the Windshield as a fixed display

There has recently been a lot of research on using the windshield as a HUD for vehicles. This has the advantage that the user doesn't have to take their eyes off the road while following navigational directions. The University of California conducted a study using the windshield as a display, using AR elements to convey an alert when the driver drives above the speed limit [25]. The study found that user's had a faster reaction time using the HUD than when using a HDD display.

Tsimhoni et al. studied the best position to present information for a driver in terms of driving performance and mental load. Their studies showed that the message locations placed at 10°to 5°from a straight gaze yielded the best performance. It was also preferred the highest by the subjects [44].

Charissis et al. tested a HUD based collision warning system that could be used in low visibility conditions. The results pointed towards significantly reduced number of collisions when compared to a HDD [24].

Using the windshield as a display has also been researched by many commercial brands in recent times. For example, Jaguar's Land Rover launched a concept video showing AR Technology used on a windshield in a car [10]. This display is interactive and has features like virtual racing lines that change colour to indicate optimum braking, and virtual cones along the road that helps train novice drivers. The most exciting feature is a ”ghost car” which is a virtual car that the driver can race with [Fig 2.1.2]

Figure 2.1.2: Ghost car concept unveiled by Jaguar
Image Credit: Jaguar Land Rover[10]

A company called Navdy [14] released a similar HUD Device in 2014 which consists of a dashboard-mounted device which projects a bright transparent image directly into your field of view [Fig 2.1.3]. This device is plugged into the car’s onboard computer and can be used to display vital information along with navigational aids. It can also be paired with a mobile phone to display text messages or calls. It has voice and gesture commands that the driver can use to control the device.

Continental is working on a AR HUD prototype which shows essential information to the driver, like current speed, distance of the car in front, turn directions, or upcoming driving conditions [1] [Fig 2.1.4]. They are set to release it some time in 2017 and also plan to make a version of the AR HUD available

Figure 2.1.3: HUD technology by Navdy
Image Credit: Navdy Website [14]

that uses a small plastic panel as the display. This helps to extend the AR HUD technology to lower priced cars.

Despite its ability to display essential information to the user without needing them to glance off the road, there is also some concern on how much HUDs can act as a distraction to the user and cause them to miss out things around them. Visibility under bright sunlight is also another concern.

2.1.2 Head Mounted Displays

Head-mounted displays (HMDs) are a type of display device worn on the head that show projected data. They have optics that are close to the eye, which give an illusion of being ”virtual displays”. In order to align virtual images with the real world, HMDs also require some head-tracking algorithms to track the movement and direction of user’s viewpoint.They provide high quality visual immersion and 3D stereoscopic depth. Despite being completely portable, it often suffers from

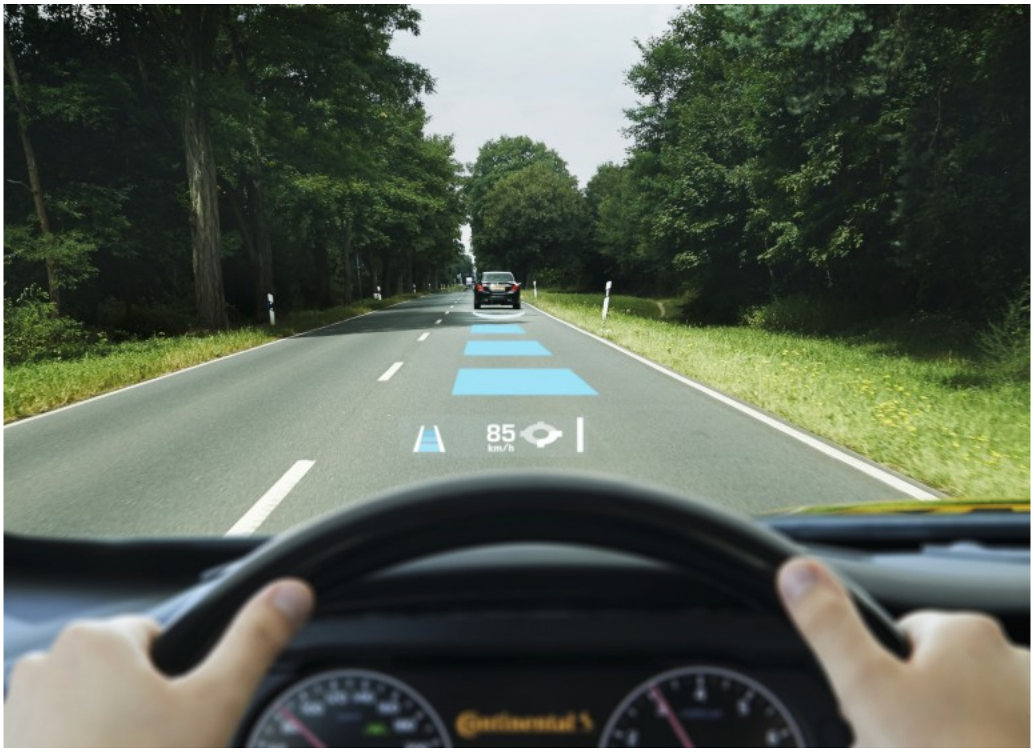

Figure 2.1.4: Continental's AR-HUD Technology
Image Credits: Continental Website [1]

low resolution and display brightness.

HMDs have been used from as early as 1960s in the earliest systems using AR, to overlay virtual graphics on to the real world. Head Mounted Displays initially had the disadvantage of being too heavy and uncomfortable, but their size has been substantially reduced recently. For example, displays like the Epson Moverio BT-200 are significantly smaller than those used a decade ago [Fig 2.1.5].

Google Glass was a significant step toward lightweight, subtle HMDs. The Google glass was developed by Google in 2013. It features a prism projector that projects data onto a small screen near the wearer's eye.[Fig 2.1.6] that emulates a 25 inch screen placed 8 feet away from the eye. The Glass is controlled using voice and a touch sensitive panel on the side of the display [8]. However, Google

Figure 2.1.5: Epson Moverio BT-200 HMD
Image Credit: Hideya HAMANO[3]

Glass has faced some criticism over its display being non-stereo and relatively low brightness.

Figure 2.1.6: Google Glass
Image Credit: Rijans007[7]

The Touring Machine developed at the University of Columbia [26] was one of the first systems which featured a HMD for outdoor navigation. The user is tracked using a satellite based GPS (Global Positioning System) and a magnetometer based orientation tracking. Using the orientation tracker, users could look around and virtual information about buildings around the user was displayed on a tracked, see through head mounted 3d display. The system also had a handheld 2d display with touch functionality as the input [Fig 2.1.7]. Despite HMDs like the Google Glass being much smaller and more comfortable than their predecessors, it still has the major disadvantage of forcing the user to carry additional equipment; a mobile phone. There is also the need for additional technology on the device or the environment to track the input to the device by the user [36]. This affects the freedom of the user and the portability of the system. Forcing the user to wear a head mounted system raises the issue where the user might not want to wear technology if they feel it negatively affects their appearance [20].

Figure 2.1.7: HMD for the Touring System [26]

A major advancement in the field of wearable displays is the release of Microsoft's Hololens [9]. It has a high definition, bright 3D optical display fitted with advanced sensors and spatial audio. The Hololens has its own dedicated CPU and GPU, and uses "air pointing" for input, where the user selects objects by pointing at them as if they had a virtual mouse [Fig 2.1.8]. The Hololens was in development for around five years before being announced in 2015. The Hololens is especially intuitive as it blends AR and VR elements. It lies in between the model targeted by the Oculus Rift (Full Immersion) and of the model by Google Glass (Glance model). The hololens permits the user to view and interact with 3D objects in their surroundings.

Figure 2.1.8: Microsoft's Hololens
Image Credit: Isriya Paireepairit[13]

There has not been much research into using HMDs while driving a vehicle and the impact it has on the user . With all the recent advancements in HMD technology, it will be interesting to see how these AR displays fare against HUDs and HDDs.

2.1.3 Fixed Console Based AR Display (Head Down Display)

A dashboard mounted console that acts like an AR Display is one of the oldest types of AR displays for in car navigation. Rendering AR elements on a handheld mobile for pedestrian or indoor navigation has also become more popular in recent times with the availability of several applications that provide this service. This is the same technology that is used in Fixed console based AR displays. The car has a forward viewing camera that provides a live video stream to the console mounted on the dashboard, usually at an angle of 30°to 45°below the driver's eye level.

Pioneer has launched their Cyber Navi line [2] which features both a HUD that is placed on the same position as the car's sun visor [Fig 2.1.9] and a fixed console on the dashboard that captures video from a camera mounted near the rear view mirror. This camera scans the road ahead and provides a live video feed to the console. The system then uses object recognition to detect street signs and traffic and presents this information in the form of AR data overlaid on the video feed.

Figure 2.1.9: Pioneer's Cyber Navi System
Image Credit: Pioneer News Release [2]

HDD technology has a clear disadvantage of needing the driver to take his or her eyes off the road to glance at the display. However this have been presented as an advantage by some researchers because with a HDD there is a lower chance of distraction than when using a HUD. There is also a lower chance of essential real world objects being obstructed by the AR elements. The low visibility of augmented elements is also not a problem in HDDs.

2.2 Results from Related Projects

Dr. Mark Billinghurst, Dr. Gun Lee and I, along with other researchers at the HIT LabNZ worked on a project whose results can also be used for this thesis research. The project involved a study to implement AR based guidance for heavy vehicles like earthmoving excavators.

Prototypes of an AR display was developed and pilot field tests were carried out to compare performance of different head mounted displays. The displays that were compared were the Epson BT-200, Vuzix M100 and Google Glass. Based on qualitative data from the questionnaire used for the pilot tests conducted, Google Glass was the overall winner, being the most comfortable and simple to use. However, its major disadvantage is its low visibility in bright sunlight. This led to the picking of Google Glass as the HMD to be used in this thesis study.

The pairwise ranking for the overall preference for each display tested are shown in Fig. 2.2.1.

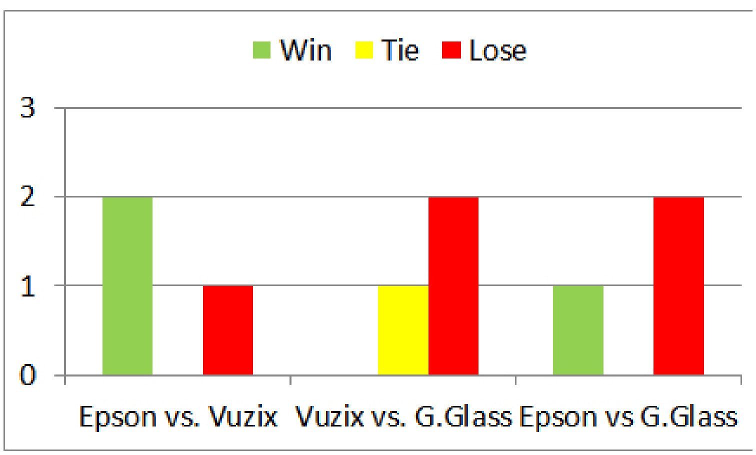

Figure 2.2.1: Pairwise ranking for overall preference

Alexandre Pereira, a colleague from the HITLab NZ conducted a study to test different interfaces and displays for navigation in a warehouse using a forklift. The

Figure 2.2.2: Field test for HMD

study involved testing of Ego-centric and Exo-centric interface designs with HMDs and HUDs. Different combinations of these conditions were tested. The subjects were asked to navigate through a warehouse in a forklift and find a specific box based on instructions provided. The displays were simulated in a VR environment using an Oculus Rift and the time for each task was measured and compared. Ego-centric interfaces had a significantly higher score than exo-centric interfaces. The feedback on the design of the HMD from pilot studies aided in design of the manner in which instructions are provided for an HMD in my study.

2.3 Research Opportunities

Using AR for automobile navigation is a researched area that has been picking interest recently. For the driver, their primary goal remains to focus on the road and so these AR technologies must only act to supplement them without affecting their normal functionality in a negative manner. Despite a large amount of research being done in this field, much of the technology has not made it past laboratory studies into commercial production. This chapter has tried to summarize some part of the interesting research that has been done in this area.

Most of the existing research compares HUDs with traditional HDDs, with some research comparing the advantages of using AR instead of traditional map navigation. There is relatively little research done on studying how a HMD used for AR based navigation compares to a HUD based AR display and a traditional console AR display. In this thesis, I will be comparing AR on different displays using qualitative and quantitative evaluations method. This research will aim to be as immersive as possible to obtain accurate results and to create a foundation for similar research in the future.

3

Design

This chapter talks about the inspiration and initial ideas that were created and iteratively evaluated until creation of the final concept. Most of the planning part of the Design Process Cycle was done at this stage

3.1 Idea Conceptualization

This section explains the process of idea generation using several methods. It starts with a brainstorming session to conceptualize ideas; Wireframes were used to lay out the ideas based on interface concepts. The last section deals with the design of the user experiment .

3.1.1 Brainstorming Session and Wireframes

A series of brainstorming sessions were conducted to help generate ideas. Some assumptions made for the brainstorming session were:

Assumption 1: While wearing a head mounted display, all information presented to the user is personal. Augmented elements are presented to the user superimposed on the real world. The see through display can display information based on the head orientation (which is tracked), and the position of the user with respect to the real world is also tracked. However, displaying too much information can clutter and obstruct the viewers view.

Assumption 2: While presenting augmented elements to the driver using a fixed Heads Up Display, the windshield is used here. Any portion of the windshield can be used as the display. The car's position is tracked and can be used to show navigation.

Assumption 3: The Heads Down Display used here is a hand held display that is mounted on the dashboard. It has a high resolution and displays live video feed from cameras mounted on the front of the car. It may have touch input and several sensors that track orientation. The relative position of the car with respect to the real world is known.

By keeping these assumptions in mind and several ideas were generated together by a collaborative effort by the other researchers at the lab.

Interface

The ideas generated by the first brainstorming session were used to decide on the essential data that should be displayed with each display. These ideas were then used to create sketches and mock-ups of the interface for each display . Two ideas were picked by each person, and the reason for the choice was explained. These reasons could be expanded based on feedback from the others. The ideas are explained below and the major ones are elaborated.

- All displays will have the same display area.
- The items to be displayed will be directions and speed.
- A warning label should be shown if the user exceeds the speed limit.
- The labels will be colour coded on various ranges of speeds;
- Navigational instructions will be presented in the same manner across all the displays.
- Navigational instructions will be presented using 2-dimensional arrows.

It was proposed that the display area for each AR Display would be the same. This is so that there would be no bias based on the size of the display. Each display will present both the navigational directions in the form of 2-dimensional arrows, as well as the driver's speed. The driver's speed is colour coded so that the driver can easily identify how close they are to the speed limit. The speed limit here is set at 60km/hr.

Based on the discussion from the brainstorming session, wireframes for the interface were made. These wireframes were used to show how the elements discussed in the brainstorming session was arranged in the display interface

Each display had:

1. Navigational Arrows are the biggest and are shown on the left half of the display.
2. Current speed is shown on the top of the right half of the display. Speeds are colour coded. Speeds till 50km/hr are shown in green, between 50-60km/hr in yellow and above 60km/hr in red.

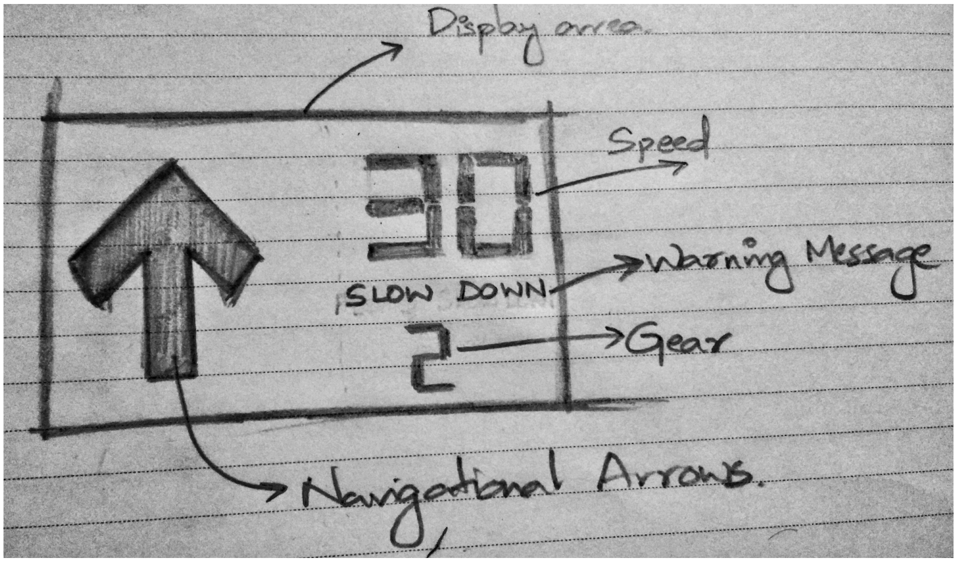

Figure 3.1.1: Interface Wireframe

3. A warning label is shown on the bottom of the right half of the display. A warning message is shown asking the driver to slow down once they exceed 50km/hr. This label is colour coded similar to the colour codes of the speeds (Yellow and red).

3.1.2 Use Cases and Users

There is an important consideration to keep in mind while designing interfaces and technology to aid with vehicle navigation. Unlike traditional technology systems where the primary task is to attend to the application, an automobile navigation system is used to supplement the driver's primary task of driving.

ISO Standards [28, 29] talk about the requirements for Man-Machine-Interfaces (MMI) in vehicles. In a vehicle, the user's tasks fall into either primary, secondary

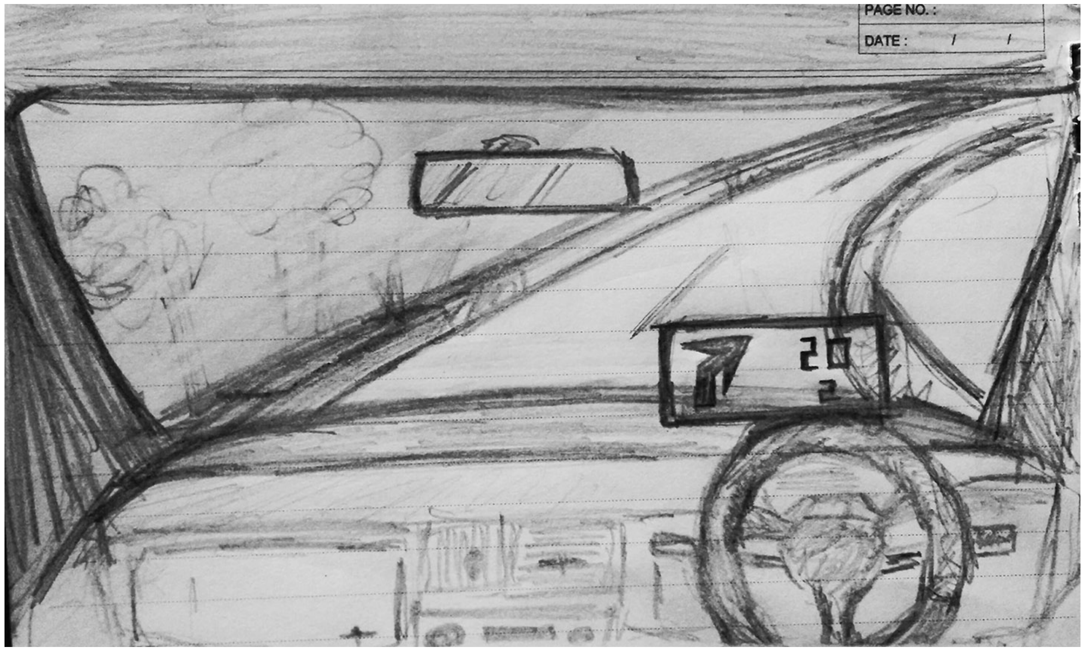

Figure 3.1.2: Windshield HUD Wireframe

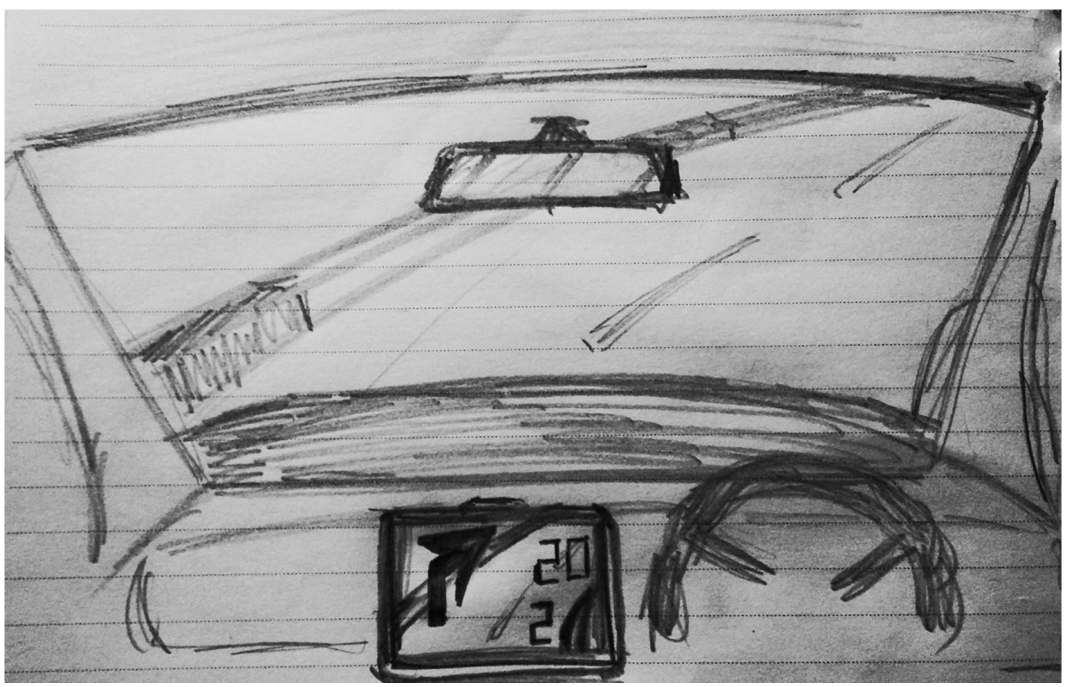
Figure 3.1.3: HDD Wireframe

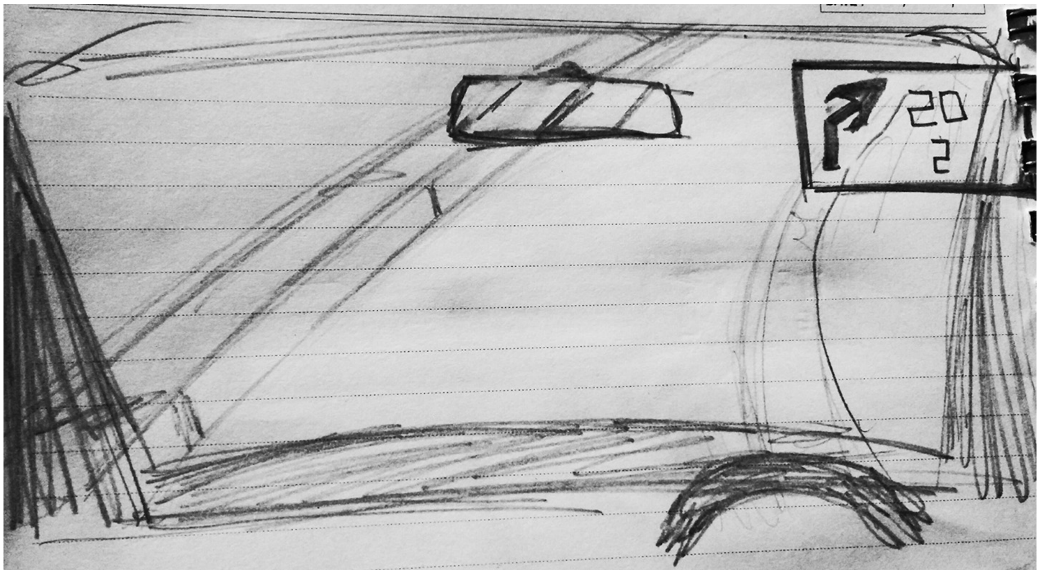

Figure 3.1.4: HMD Wireframe

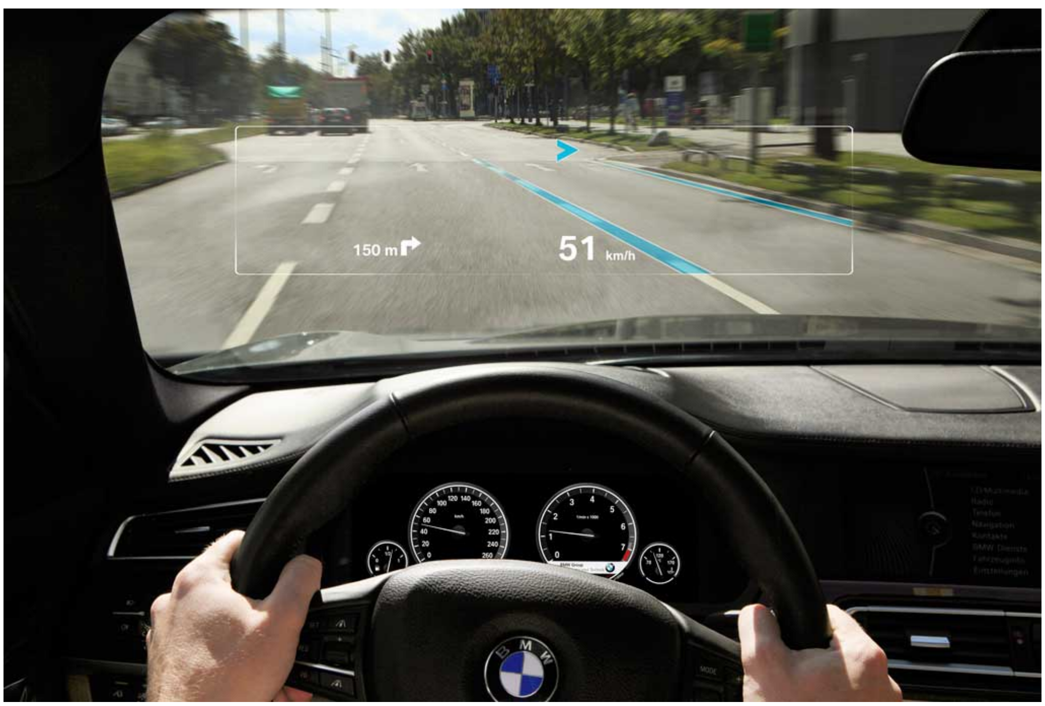

Figure 3.1.5: An example of AR Navigational System. Credits: BMW AR Technology

and tertiary categories[30]. Each of these tasks are divided into separate physical areas in the driver's user space. The primary task involves the maneuvering of the vehicle while keeping an eye on the surroundings and distance to other cars and objects. Secondary tasks are those that supplement the primary tasks like controlling the turning indicators or windshield wipers. Tertiary tasks provide entertainment and do not have any relationship with driving. There have been many studies which prove the superiority of Heads Up Displays (where the display is at 5°-10°below the eye level) over Heads Down Displays (where the display is at 20°-40°below the eye level)[27, 37]. Having a screen fixed display might have advantages like having information available even when the driver looks around while driving.

Some of the primary tasks that a user has to accomplish while driving are:

- Maneuver the vehicle.
- Control of speed.
- Be aware of surroundings and control of distance to other objects (and other cars).
- Way finding and navigation.

This system also has some physical requirements:

- It should be comfortable for daily use. If wearable (In the case of HMDs), it should be lightweight and portable.
- It should not affect the visibility of the surroundings.
- The graphics on the display should be clearly visible.
- It should be simple, easy to understand and follow.
- It should be easy to multitask maneuvering and following directions on the display.

We are especially concerned with how Head Mounted Displays fare in navigation when put against Head Up Displays. This is calculated by presenting navigation directions to the user using each display and comparing different parameters that affect their driving. Ideally the driver should be able to navigate to their destination with least errors possible, without having the graphics on the display distract them from driving or clutter their view.

The design of the interface had a few challenges. For this experiment, the interface and the display area was to be same for each AR display, so the interface should be designed in such a way that the information would be visible properly in each case. Another challenge was deciding what information should be presented to the user. The splitting of navigational instructions from the speed and position for textual warning messages was so that the user could identify the type of information more quickly before needing to focus on the information on the display. The colour coding of the warning messages also boosts this factor.

4 Implementation and Prototyping

After arriving on a design concept based on brainstorming and wireframes, the next step was to implement a working prototype based on the designs. This chapter explains the various hardware and software components used to construct the prototype. This prototype would later be used to conduct user evaluation tests (which will be described in the next chapter). The HMD will be referred to as Google Glass HMD and the fixed console display as AR Lens from this chapter for easy understanding.

4.1 Hardware

4.1.1 Available Technology

Some of the technology available for me to do the user study at the HIT Lab NZ is described below.

Display

This section describes the different simulated AR display devices and the virtual environment used to show them.

Multiple Displays: The most common type of display solution used for testing driving prototypes are ones that consist of a tiled display system using multiple monitors/displays.

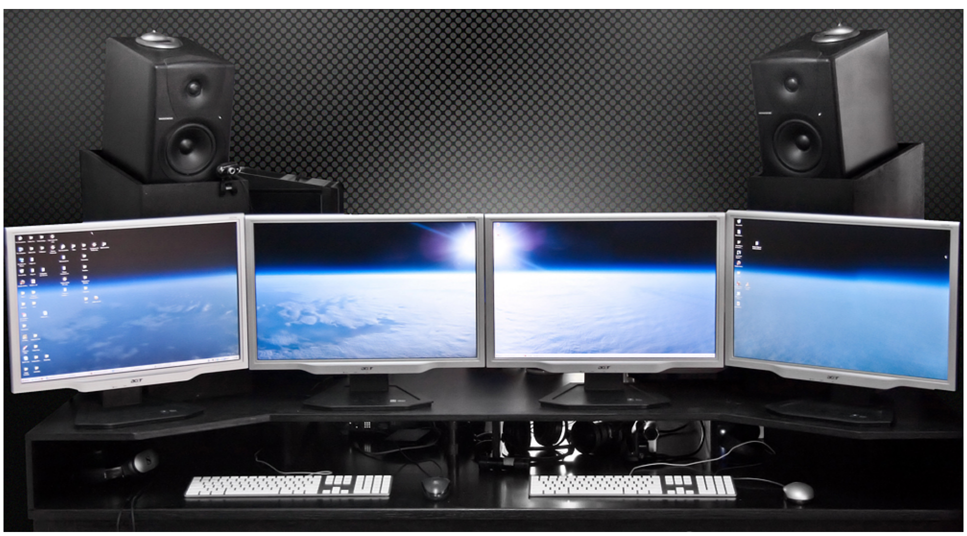

Figure 4.1.1: Multiple Monitor Setup
Image Credits: Wikipedia-Multi Monitor[12]

Even though it has an advantage of being simpler to set up for a smaller area of view, it is much harder when a larger area is required.

VisionSpace: The HIT Lab NZ has it's own Virtual Reality and Visualization facility. End-users can view and interact with 3D virtual data in real time. The facility can be used for research, user studies and prototypes.

Figure 4.1.2: HitLabNZ's VisionSpace Facility

There are four main environments in the Vision Space Facility:

- The VisionSpace Theatre: The most immersive experience of the four environments, it consists of a three screen stereo projection system that has a 6 Degree of Freedom tracking system. It can render a 120°wide field of view, showing both 2D and 3D content. It also has a high end spatial sound that adds to the immersive experience [Fig. 4.1.2].
- The VisionSpace Wall: This tiled display is a solution for 3D visualization. It is often used for 3d simulation analysis and ultra high-resolution image analysis.
- The VisionSpace Desktop: Often used to test prototypes and for high quality 3D applications before deploying it on the VisionSpace Wall / Theatre. Equipped with high quality 3D stereo.

- The VisionSpace Portable: Supporting high quality 3D graphics and 3D stereo, this mobile solution is often used for conferences, presentation, etc...

Occulus Rift DK2: The Oculus Rift is a VR HMD developed by Oculus VR[18]. They released their first Development Kit (DK1) in 2012 and the second Development Kit (DK2) in mid 2014 [16, 18]. The Oculus Rift is a simple and lightweight VR headset that provides an immersive virtual world experience. It is often used to develop VR experiences for games, where the user steps into a game and allows them to look around and see the virtual environment in 3D all around them.

Figure 4.1.3: Oculus Rift
Image Credits: Merlijn Hoek[17]

The Rift has 3 DOF head-tracking, and a wide field of view of 110°diagonally and 90°horizontal providing a very realistic and immersive experience. The rift has a 7" flat LCD display (60 Hz), divided by 640x800 pixels per eye. It supports a resolution of 1280x800 px (720p HD resolution). The user views the screen through two lens and there is a 2.5" fixed distance between the lens. The device also comes with an orientation and motion sensor (sampling rate of 1000Hz). It has it's own gyroscope, magnetometer, an accelerometer, and an ARM Cortex M3 microcontroller. These sensors allow it to track your head movement as the user looks around the virtual environment in real time.

Even though the Oculus Rift provides a good immersive experience, it sometimes has been known to cause motion sickness in users. This is caused due to sensory conflict caused between the information conveyed to the visual senses showing that the wearer is moving, while the vestibular sensors tell the brain that user is fixed in place. The sluggish motion is also another factor. A few solutions have been introduced with the DK2 to combat this problem. One is to replace the LCD with a low brightness OLED display that is not as sluggish as the earlier LED display.

Input

Ferrari Thrustmaster GT Steering Wheel: The Ferrari Thrustmaster GT Steering Wheel [Fig. 4.1.4] was used as the main user input device. It is manufactured under official Ferrari® license and comes with a central attachment system that provides optimum stability for the wheel. The wheel also has digital gear shift levers located on the side of the wheel along with pedals featuring an attached footrest. It provides comfortable braking (having a resilient brake pedal) and acceleration. The wheel also has auto-centering, adjustable wheel sensitivity, and force feedback with realistic resistance which makes the driving experience as realistic as possible [4].

4.1.2 Final System

The final system used consists of an Oculus Rift as the VR display and the Ferrari Thrustmaster GT Steering wheel.

Figure 4.1.4: Ferrari Thrustmaster GT Steering Wheel
Image Credits: Nadir Hashmi[5]

The Oculus Rift was preferred over the other displays due to its highly realistic and immersive experience and also has the capability to track the user's head orientation and move it in a similar fashion within the virtual environment.

The Vision Space would provide a highly realistic option if used but computer graphics could only be displayed on the front and the two sides of the user while the Oculus shows a fully 3d environment where the user could view every degree of their environment. Another reason was that the development of software that can be run on the Oculus is also much simpler due to integration with Unity and Unreal Game Engine when compared with programming for the Vision Space. The difficulty in developing a method to represent the windshield AR display in a convincing manner for the Vision Space was another reason for picking the Oculus Rift. The motion sickness disadvantage is considerably minimized in the DK2 of the rift using the head tracking camera and the more responsive OLED display. Using the combination of the Rift and the steering wheel, the user would feel fully engrossed in the simulation of using each display as they drive around in

the virtual environment.
For this study, simulations of each of the AR displays using the Oculus Rift are compared.

4.2 Software

The virtual simulation was developed using Unity v4.5. Unity Game engine is cross platform and is used for development of video games. Unity is well known for being powerful and yet being simple to develop in. It is known for being able to target a large amount of platforms.

The aim of the application is to simulate the use of each AR display in driving situations. To make the scenario as close to real world as possible, there are a few requirements for the development of the prototype. These are:

- It should require the user to look around.
- It should require the user to navigate based on instructions shown on the AR display.
- It should require the user to navigate without colliding with the environment.
- It should require the user to pay attention to maintaining their driving speed to within the speed limit.

The development of the prototype is split into smaller modules. Each module is explained separately.

4.2.1 Car Model

The development made use of the UnityCar 2.2 Plugin for the car model [19]. Unity Car 2.2 is a high quality plugin that provides a realistic simulation of

Figure 4.2.1: Top view of UnityCity Environment

vehicles for the Unity Game Engine. Unity Car is also easy to integrate with already existing code with a little scripting [19]. The car models provided by the plugin have realistic vehicle physics to make the simulation believable.
The car used was a left-hand traffic drive model. A few tweaks that were added to the car model was the addition of a character model in the driver seat as well as syncing it with the steering wheel and pedals. A certain button was programmed to be the car's horn, and the number of times this button was pressed was recorded in a text file. The car could be driven as an automatic or manual transmission. The gear and speed that the car is currently in is recorded so that it can be displayed in the AR display module.

4.2.2 City Environment

The city environment used for this prototype was the Unity City terrain provided by UnityCar 2.2. The Unity City terrain is an extensive city model that has various roads and buildings. It also had a highway system that ran around the map. Sunlight was emulated using light from a point light source. The map has a complicated system of interconnected roads that could be used to navigate to a pre-determined fixed position using different routes that have the same distance and equal number of turns [4.2.1].

4.2.3 Cameras

This module deals with placement of cameras in the Unity project scene. The Oculus SDK for Unity provides some prefabs (Prefabs in Unity are reusable objects/assets within the project) for the Oculus Camera, known as the OVRCameraRig. The OVRCameraRig consists of 3 separate cameras placed together looking left, center and right respectively. This prefab is added to the scene to emulate the driver's point of view in the car.
The car model is also tweaked using multiple cameras to add the side and central rear view mirrors. There is also a forward camera added for the Fixed console AR Lens.

4.2.4 AR Display Simulation

Most of the development work of the prototype was concentrated in this section. Each display simulation was created and it was possible to switch then for each test iteration. The implementation of each AR display was done using the NGUI Plugin for Unity [15]. NGUI is useful in implementing User Interface systems. In this case, NGUI is useful in implementing 2D User Interfaces for the displays that are overlaid onto the virtual 3D environment.

Windshield HUD AR display

The Windshield AR Display simulation was developed using NGUI to create an area on the windshield to display instructions for navigation and to indicate the speed (based on the interface concept discussed in the design section). The interface was created and displayed in the bottom center of the windshield (based on studies showing this as the ideal position) [44].

(a) Windshield Display **(b)** Google Glass HMD

Figure 4.2.2: Windshield and Google Glass AR Simulation

HMD similar to Google Glass

The HMD AR simulation was developed similar to the Windshield AR Display. However, the display screen was positioned so that it would be displayed on the top right corner of the user's view, similar to the view through the Google Glass' display. Since this type of AR Display is only fixed relative to the user's view, the display screen is attached to the OVRCameraRig. This way the display remains fixed as the orientation of the camera changes.

Fixed Console HDD AR Display

The fixed console AR Display had its display screen fixed onto a model of a console mounted on the dashboard. This console had a base screen layer showing live feed from the camera positioned in front of the car. The AR screen was overlaid on top of this feed. As discussed earlier, the console was placed at approximately 30°below the eye level.

Figure 4.2.3: Fixed HDD AR Lens Implementation

4.3 Summary

The development of the prototype was described in this chapter along with reviews on the different available technologies for hardware (And also explained which hardware system was ultimately selected and the reason for the same). The main modules involved in the development of the prototype software were also explained briefly. Most of the programming for the software was done using C# and Javascript in Unity. The use of plugins like NGUI, UnityCar 2.2 helped in a faster development of a virtual environment that aimed to be as realistic as possible. To evaluate this system, a user experiment is designed and data obtained is analyzed. This is explained in detail in the following chapters.

5
Evaluation

This chapter describes a user study conducted to compare between the different simulated AR displays for vehicle navigation. This chapter is split into several sections. The section about the goals of the experiment is explained first, this is followed by the description of the user study. Finally the results of the study and its analysis is presented. The information consent form and the subject questionnaire can be found in Appendix A.

5.1 Goal of the evaluation

The goal of the evaluation is to compare the effects of using different types of AR displays for navigation while driving. To achieve this, a user study was carried out to compare the effects of the displays on driving. This includes both qualitative and quantitative measurements based on performance and personal responses of the subjects.

5.2 Experiment Design

5.2.1 Hypothesis

The main hypotheses for the design are:

- **Hypothesis 1:** There is no significant difference in navigational errors made when using a Head Mounted AR Display (similar to Google Glass), Windshield Heads Up AR Display and a dashboard mounted fixed console AR display.

- **Hypothesis 2:** There is no significant difference in other aspects of driving that were affected when using a Head Mounted AR Display (similar to Google Glass), Windshield Heads Up AR Display and a dashboard mounted fixed console AR display like the amount of surrounding objects detected and ability to keep within the speed limit.

The number of navigational errors made was compared when using the Windshield HUD, the Google Glass like HMD and a fixed dashboard console for presenting navigational data with AR.

The effect on overall driving is studied and compared when using the Windshield HUD, the Google Glass like HMD and a fixed dashboard console for presenting navigational data with AR.

Even though Heads Up Displays have been known to have advantages over traditional Heads Down Displays, each type of simulated AR display has its own disadvantages and advantages. Based on recent research that shows that AR when used for information presentation can prove advantageous, it is hard to predict how each of the AR displays will affect the number of navigational errors and their impact on overall driving. This lead to the formulation of Hypothesis 1 and Hypothesis 2.

5.2.2 Materials

The user study was conducted in a small room (3m x 5m). The materials used for the study were:

- A desktop computer.
- An Oculus Rift.
- An Audio Technica ATH-ANC33iS Noise-Cancelling Headset.
- A Ferrari GT Thrustmaster Steering Wheel and pedals.
- Two chairs.
- Two tables.

The two tables are placed back to back lengthwise. One table was used by the experimenter and the other by the subject. The desktop computer was placed on the experimenter's table and the monitor was placed so that the subject could not see what was on it. The chairs were placed on either side and the steering wheel was attached to the subject's table and the pedals were positioned on the floor. The side of the table has ample space for the subject to read and fill out the questionnaire forms. The headphones were connected to the back of the desktop computer (Audio Port) so that it reached the subject perfectly. The Oculus was connected in a similar fashion and reached to the subject's side. The Oculus has an HDMI display cable, a power cable and a USB cable which were all connected. All the cables were secured together using tape to avoid any kind of clutter or confusion and so that the equipment could be comfortably used by the subject [Fig. 5.2.1].

Figure 5.2.1: Experimental Setup

5.2.3 Procedure

To test various AR Displays for navigation using virtual simulation with Oculus Rift, a within-subject study was conducted with three conditions. The dependent variables were:

- Number of wrong turns made.
- Number of times exceeding the speed limit.
- Amount of time spent above the speed limit.
- Number of objects detected in the surroundings.

The three conditions chosen were:

- HUD: A windshield AR display simulation
- HMD: A Google Glass AR simulation
- HHD: A fixed dashboard mounted AR console

In each of the three conditions, the subject was required to fulfill three tasks to the best of their ability.

- Follow navigational instructions provided to the subject through the AR Display simulation (based on condition chosen) on the Oculus.
- Follow the speed limit of 60km/hr
- Look around for the model of a character placed around the map and click a button on the steering wheel every time a character is seen.

The order of selecting each condition per subject was varied with the use of a Latin Square in order to counterbalance the learning effect. The information sheet and the consent form was first provided to the subject at the start of the user test. The subject read the information sheet and signed the consent form. The research was then explained to the subject along with how each AR Display would look. The tasks to be completed by the subject was then explained to them.

Once the system was explained to the subject, the researcher assisted the subject in putting on the equipment. The subject was first asked to adjust their chair and sit so that the steering wheel and the pedals were at a comfortable position that was easy to use. The subject was then helped to wear the Oculus Rift and headphones.

The experiment tried to identify the effect of following instructions displayed using each AR display on the driving of the subject. Navigational instructions were provided to the subject to be displayed in each simulated AR display. The subject navigated through the city simulated in the Oculus, following these instructions. The subject was also required to keep below the speed limit. A character model shown to the subject before the experiment was placed on certain positions (like intersections) throughout the city. The subject had to look around for these models as they drove and click a button on the steering each time they saw the model. This was added in order to calculate how attentive the user was to his or her surroundings while following navigational instructions. This also ensured that the user looked around at intersections and corners similar to real life driving conditions.

The user was first allowed to drive freely for 2 minutes in order to familiarize themselves with the system. After this is done, a condition was picked using the Latin Square design and the user was asked to complete the tasks mentioned above. The results of these tasks were logged into a text file.

After the subject successfully drover to the pre-determined destination following all the navigational instructions provided to them, they were asked to fill a questionnaire on comfort, usability and efficiency of each AR Display simulation.

When the questionnaire was completed, the next test condition was started.

At the end of all three test conditions, the subject was also asked to fill in a questionnaire about demographic data like age, gender, experience with driving, previous experience with the Oculus Rift and VR. They were also asked to rank the three conditions based on the order of their preference along with reasons for their choice.

5.2.4 Measurements

There were several quantitative measurements that were recorded for the study. Most of these measures were recorded using the application itself while the qualitative measures were captured using the questionnaires.

The number of navigational errors were measured based on the number of wrong turns the subject makes as they tried to navigate based on the instructions (using 2D arrows) provided to them for each condition. Each time the subject made a wrong turn this was recorded. The number of correct turns that a user made was also recorded. Since every time the user made a wrong turn, the length of the route changed, we use a ratio of the number of wrong turns to the number of correct turns for measurement. The task was completed when the subject reached a predetermined destination point on the map.

As the subject tried navigating through the city simulation, they were expected to maintain the speed limit of 60km/hr. Every time the subject exceeded the speed of 62km/hr, the application logged the instance. It also recorded the time the user spent above this speed until they went back to below the speed limit. This could be used to identify the time the user took with each AR display above the speed limit (the time the user took to realize that they had crossed the speed limit).

One of the main requirements for a user when they were driving was to be aware of their surroundings and identifying hazards. This was tested by placing a character model at different positions throughout the map. The subjects were asked to look around as they were driving and to click a button when they spotted the character model. The number of clicks was logged, to help understand the level of concentration each AR display required from the subject while driving so that they did't notice the model characters around them.

The questionnaire was used to record the subject's demographic data, information on their history with using VR, Oculus Rift and also the number of years they have been driving. The questionnaire had qualitative questions about the subject's view of each of the condition. The questions were easy to understand and used a 7-point Likert Scale. These questions are discussed later on in this chapter.

5.2.5 Participants

Three subjects were selected for the initial pilot test. The results obtained from the pilot tests did not count toward the results of the study. They were used in the experiment in order to test the system and detect early bugs before the real trials. They also helped in tweaking and improving the questionnaire so that it can be easier to understand by the participants. 19 people were asked to participate for the study but data from only 18 participants were used. One subject's data was not used because they had very limited driving experience (less than 2 days of actual driving experience). The user found it very difficult to drive as they were not at all comfortable with driving controls and could not navigate to the destination. Among the remaining subjects, most of the subjects were students from the University of Canterbury. Among the 18 subjects for the study, 4 (22%) were female and 14 (78%) were male. Most of the participants were aged between 20 and 35 years (Mean: 25.5 years). Some of the subjects held driving licenses from multiple countries. The experience of participants with driving ranged from 1 - 10 years (Mean: 6.8 years). Several subjects had experience with using the Oculus Rift, but even this was basic experience. Around 33% of participants wore glasses while driving, but this did not affect the experiment as they wore the glasses while performing the experiment.

5.3 Results

The first part of this section discusses the quantitative data that was recorded by the system during the user experiment. The second part tries to explain the quantitative data recorded using the Likert scale questions in the questionnaire followed by the last part that describes the qualitative data obtained though the open questions the subjects were asked with the questionnaire.

5.3.1 Quantitative Measures: System

The quantitative measures recorded by the system were the ratio of navigational errors made, the number of times exceeding the speed limit (count), the time spent above the speed limit, number of character models detected (count). The data failed the test for normality, as a result, the Friedman test was used to evaluate significance of the data from this within-subject experiment. For each result that had significant data, the post-hoc test done was the Wilcoxon-Signed Rank Test that compared each condition in pairs.

Ratio of navigational errors

As mentioned earlier, the ratio of navigational errors are recorded (Number of wrong turns divided by the number of correct turns).

Condition	Mean	Std. Dev.	25th	50th(Median)	75th
HUD	0.1640	0.16717	0.0538	0.1025	0.3000
HMD	0.5260	0.4971	0.1290	0.4055	0.7188
HDD	0.4052	0.36196	0.0925	0.4305	0.5588

Table 5.3.1: Ratio of navigational Errors: Descriptive Statistics

Table 5.3.1 shows the ratio of navigational errors the subjects took with each condition. There was a statistically significant difference in the relative number of wrong turns a user made with each type of AR Display, $\chi2(2) = 15.746$, $p = 0.000$ ($p<0.05$) [Table 5.3.3].

Condition	Mean Rank
HUD	1.31
HMD	2.61
HDD	2.08

Table 5.3.2: Ranks

N	18
Chi-Square	15.746
df	2
Asymp. Sig.	.000

Table 5.3.3: Friedman Test Statistics

Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Median (IQR) levels for HUD, HMD and HDD running trials were 0.1025(0.0538 to 0.3000), 0.4055 (0.1290 to 0.7188) and 0.4305(0.0925 to 0.5588) respectively.

Value	HUD-HMD	HDD-HMD	HUD-HDD
Z	-3.027^{b}	-1.111^{b}	-2.676^{b}
Asymp. Sig (2-tailed)	.002	.267	.007

Table 5.3.4: Wilcoxon Signed Ranks Test

b. Based on positive ranks.

There was a statistically difference in ratio of wrong turns a user made in HUD vs HDD ($Z = -2.676$, $p = 0.007$) and for HUD vs HMD ($Z=-3.027$, $p=0.002$). However there was no significant findings for number of wrong turns a user made for HDD vs HMD ($Z=-1.111$, $p=0.267$) [Table 5.3.4].

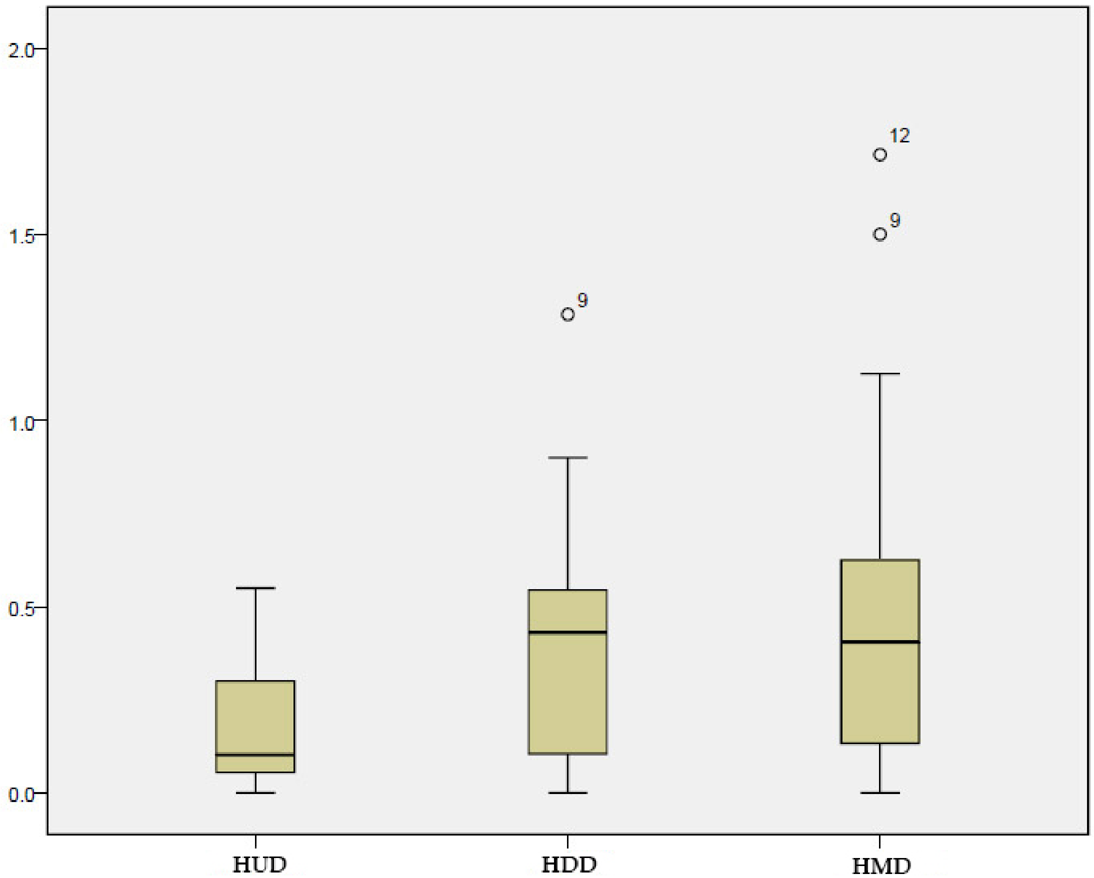

Figure 5.3.1: Boxplot of Ratio of navigational errors

Times exceeding speed limit

Condition	Mean	Std. Dev.	25th	50th(Median)	75th
HUD	.5000	.70711	.0000	.0000	1.0000
HDD	2.2222	3.00109	.0000	.5000	4.2500
HMD	.5556	.78382	.0000	.0000	1.0000

Table 5.3.5: Count of times exceeding speed limit: Descriptive Statistics

Table 5.3.5 shows the number of times the subject exceeded the speed limit with each condition. There was a statistically significant difference in the number of times the subject exceeded the speed limit in each condition, $\chi2(2) = 10.595$, $p = 0.005$ ($p<0.05$) [Table 5.3.7].

Condition	Mean Rank
HUD	1.72
HDD	2.44
HMD	1.83

Table 5.3.6: Ranks

N	18
Chi-Square	10.595
df	2
Asymp. Sig.	.005

Table 5.3.7: Friedman Test Statistics

Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Median (IQR) levels for HUD, HDD and HMD running trial were 0(0 to 1), 0.5 (0 to 4.25) and 0 (0 to 1), respectively.

There was a statistically significant difference in times exceeding the speed limit in the HDD vs HUD ($Z = -2.675$, $p = 0.007$) and for HMD vs HDD ($Z=-2.442$,

Value	HDD-HUD	HMD-HDD	HMD-HUD
Z	-2.675[b]	-2.442[c]	-.333[b]
Asymp. Sig (2-tailed)	.007	.015	.739

Table 5.3.8: Wilcoxon Signed Ranks Test
b. Based on negative ranks.
c. Based on positive ranks.

p=0.015) . However there was no significant findings for times exceeding the speed limit for HMD vs HUD (Z=-0.333, p=0.739). [Table 5.3.8].

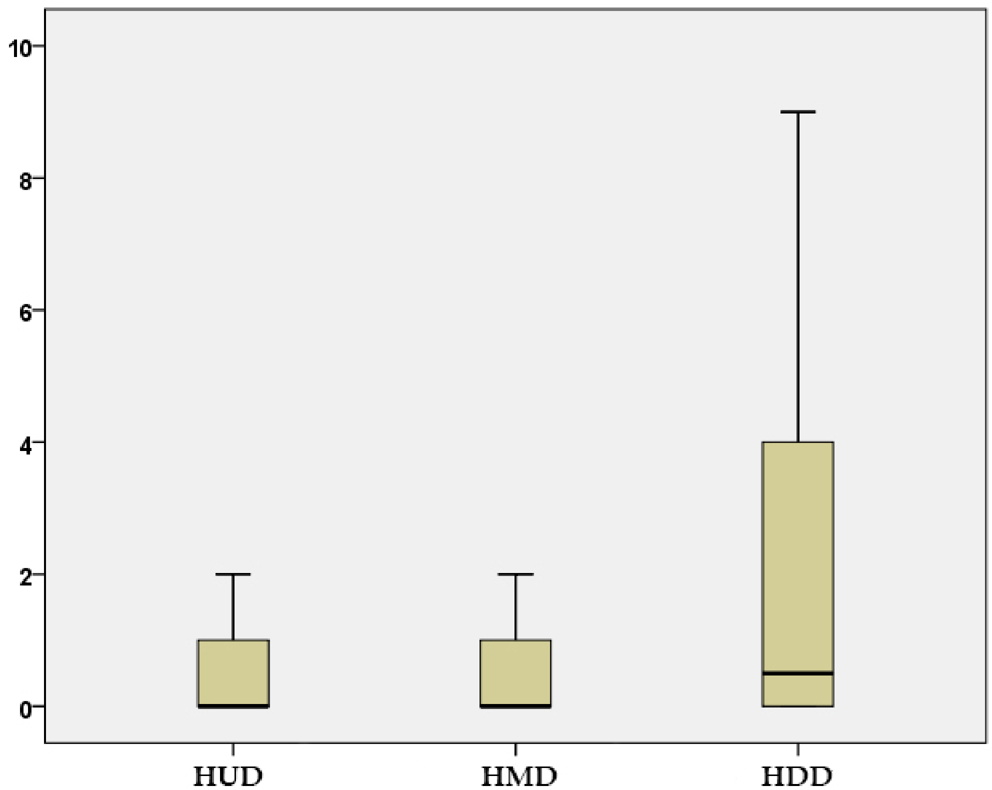

Figure 5.3.2: Boxplot of number of instances of crossing speed limit

Times spent above speed limit

Condition	Mean	Std. Dev.	25th	50th(Median)	75th
HUD	35.4444	70.56930	.0000	.0000	42.0000
HDD	167.5556	235.39409	.0000	45.0000	368.5000
HMD	35.3889	73.2322	.0000	.0000	27.0000

Table 5.3.9: Time spent above speed limit: Descriptive Statistics

Table 5.3.9 shows the amount of time the subject spent above the speed limit with each condition. There was a statistically significant difference in the amount of time the subject spent above the speed limit in each condition, $\chi2(2) = 7.091$, $p = 0.029$ ($p<0.05$) [Table 5.3.11].

Condition	Mean Rank
HUD	1.72
HDD	2.39
HMD	1.89

Table 5.3.10: Ranks

N	18
Chi-Square	7.091
df	2
Asymp. Sig.	.029

Table 5.3.11: Friedman Test Statistics

Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Median (IQR) levels for HUD,HDD and HMD running trial were 0(0 to 42), 45 (0 to 368.5) and 0 (0 to 27), respectively.

There was a statistically significant difference in times exceeding the speed limit in the HDD vs HUD ($Z = -2.599$, $p = 0.009$) and for HMD vs HDD ($Z=-2.432$,

Value	HDD-HUD	HMD-HDD	HMD-HUD
Z	-2.599[b]	-2.432[c]	-.255[b]
Asymp. Sig (2-tailed)	.009	.015	.799

Table 5.3.12: Wilcoxon Signed Ranks Test
b. Based on negative ranks.
c. Based on positive ranks.

p=0.015) . However there was no significant findings for times exceeding the speed limit for HMD vs HUD (Z=-0.255, p=0.799). [Table 5.3.12].

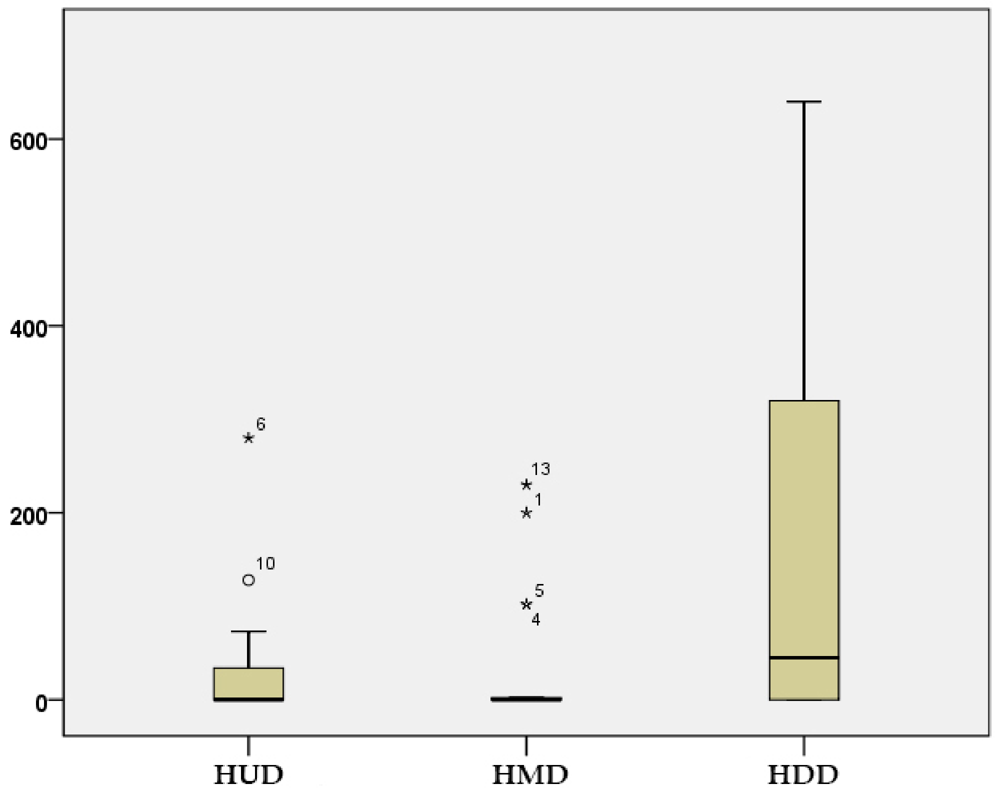

Figure 5.3.3: Boxplot of time spent above speed limit

Number of character models found

Condition	Mean	Std. Dev.	25th	50th(Median)	75th
HUD	14.3889	3.29240	11.7500	14.0000	18.0000
HDD	9.7222	4.15587	7.0000	10.0000	12.0000
HMD	12.3889	4.42106	9.5000	12.5000	17.2500

Table 5.3.13: Number of character models found: Descriptive Statistics

Table 5.3.13 shows the amount of time the subject spent above the speed limit with each condition. There was a statistically significant difference in the number of character models detected with each type of AR Display, $\chi2(2) = 6.971$, $p = 0.031$ [Table 5.3.15].

Condition	Mean Rank
HUD	2.36
HDD	1.53
HMD	2.11

Table 5.3.14: Ranks

N	18
Chi-Square	6.971
df	2
Asymp. Sig.	.031

Table 5.3.15: Friedman Test Statistics

Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$.Median (IQR) levels for HUD, HDD and HMD running trial were 14(11.75 to 18), 10 (7 to 12) and 12.5 (9.5 to 7.25), respectively.

There was a statistically significant difference in the number of character models detected in the HDD vs HUD($Z = -2.953$, $p = 0.003$). However there was no

Value	HDD-HUD	HMD-HDD	HMD-HUD
Z	-2.953[b]	-2.040[c]	-1.357[b]
Asymp. Sig (2-tailed)	.003	.041	.175

Table 5.3.16: Wilcoxon Signed Ranks Test
b. Based on positive ranks.
c. Based on negative ranks.

significant findings for the number of character models detected for HMD vs HUD (Z=-1.357, p=0.175) and for HMD vs HDD (Z=-2.040, p=0.041) . [Table 5.3.16].

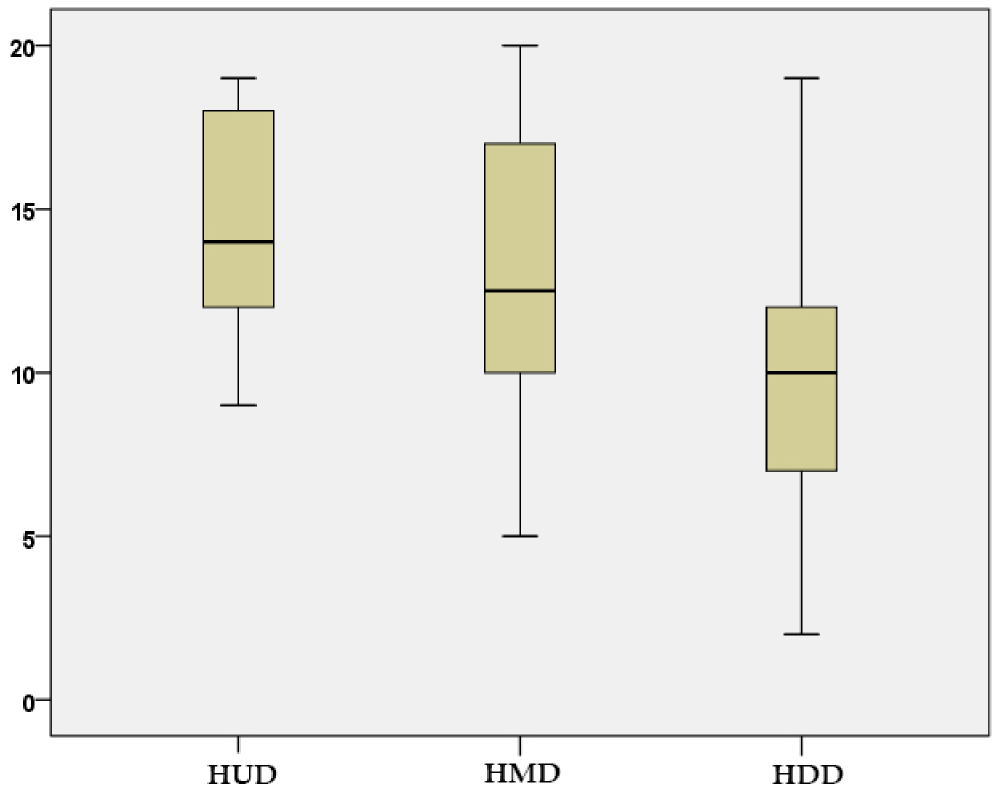

Figure 5.3.4: Boxplot of number of character models found

5.3.2 Quantitative Measures: Questionnaire

The questionnaire had 7 quantitative questions that could be answered using a Likert scale from 1 (Totally Disagree) to 7 (Totally Agree). There was also one section where the subject could rank the display in the order of their liking, from 1(Best) to 3(Worst). A Friedman test is used to evaluate statistical significance. For cases where the Friedman test yields a p-value less than 0.05, a post-hoc analysis using Wilcoxon signed-rank test is conducted to determine the pairs that have statistically significant differences. Since multiple comparisons are done, Bon Ferroni adjustment is applied to obtain an adjusted significance value of $p < 0.017$ (0.05/3=0.017).

Using this display distracted me from driving

Condition	Mean Rank
HUD	1.31
HDD	2.19
HMD	2.50

Table 5.3.17: Ranks

N	18
Chi-Square	16.097
df	2
Asymp. Sig.	.000

Table 5.3.18: Friedman Test Statistics

Analysis usinng Friedmn test shows a significant result of $\chi2(2)$=16.097, p=.000 ($p<0.05$). Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$ [Table 5.3.18].

Value	HDD-HUD	HMD-HDD	HMD-HUD
Z	-2.954[b]	-1.390[b]	-3.363[b]
Asymp. Sig (2-tailed)	.003	.165	.001

Table 5.3.19: Wilcoxon Signed Ranks Test
b. Based on negative ranks.

There was a statistically significant difference in the rating by the subjects in terms of higher distraction during driving for the HDD vs HUD($Z = -2.954$, $p = 0.003$) and for HMD vs HUD ($Z= -3.363$, $p=.001$). However there was no significant findings in the rating by the subjects in terms of higher distraction during driving for HMD vs HDD ($Z=-1.390$, $p=0.165$) [Table 5.3.19].

It was easy to navigate using this display

Condition	Mean Rank
HUD	2.69
HDD	1.69
HMD	1.61

Table 5.3.20: Ranks

N	18
Chi-Square	15.700
df	2
Asymp. Sig.	.000

Table 5.3.21: Friedman Test Statistics

Analysis usinng Friedmn test shows a significant result of $\chi2(2)=15.700$, $p=.000$ ($p<0.05$). Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$ [Table 5.3.21].

Value	HDD-Windsh.	HMD-HDD	HMD-Windsh.
Z	-3.037[b]	-.343[b]	-3.347[b]
Asymp. Sig (2-tailed)	.002	.731	.001

Table 5.3.22: Wilcoxon Signed Ranks Test
b. Based on positive ranks.

There was a statistically significant difference in the rating by the subjects for ease of navigation for the HDD vs HUD(Z = -3.037, p = 0.002) and for HMD vs HUD (Z= -3.347, p=.002). However there was no significant findings in the rating by the subjects for ease of navigation for HMD vs HDD (Z=-.343, p=0.731) [Table 5.3.22].

This display helps me in multitasking between maintaining ideal speed, looking around and navigation

Condition	Mean Rank
HUD	2.61
HDD	1.83
HMD	1.56

Table 5.3.23: Ranks

N	18
Chi-Square	12.125
df	2
Asymp. Sig.	.002

Table 5.3.24: Friedman Test Statistics

Analysis usinng Friedmn test shows a significant result of $\chi2(2)=12.125$, p=.002 ($p<0.05$). Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$ [Table 5.3.24].

Value	HDD-Windsh.	HMD-HDD	HMD-Windsh.
Z	-2.890[b]	-.779[b]	-3.139[b]
Asymp. Sig (2-tailed)	.004	.436	.002

Table 5.3.25: Wilcoxon Signed Ranks Test
b. Based on positive ranks.

There was a statistically significant difference in the rating by the subjects for ease of multitasking for the HDD vs HUD(Z = -2.890, p = 0.004) and for HMD vs HUD (Z= -3.139, p=.002). However there was no significant findings in the rating by the subjects for ease of multitasking for HMD vs HDD (Z=-.779, p=0.436) [Table 5.3.25].

I WOULD BE COMFORTABLE IF ASKED TO USE THIS AR DISPLAY REGULARLY WHEN I DRIVE

Condition	Mean Rank
HUD	2.47
HDD	1.94
HMD	1.58

Table 5.3.26: Ranks

N	18
Chi-Square	8.633
df	2
Asymp. Sig.	.013

Table 5.3.27: Friedman Test Statistics

Analysis usinng Friedmn test shows a significant result of $\chi2(2)=8.633$, p=.013 ($p<0.05$). Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$ [Table 5.3.27].

Value	HDD-Windsh.	HMD-HDD	HMD-Windsh.
Z	-1.551[b]	-1.535[b]	-2.495[b]
Asymp. Sig (2-tailed)	.121	.125	.013

Table 5.3.28: Wilcoxon Signed Ranks Test
b. Based on positive ranks.

There was a statistically significant difference in how comfortable a subject would be with regular use of HMD vs HUD(Z = -2.495, p = 0.013). However there was no significant findings in how comfortable a subject would be with regular use of multitasking for HMD vs HDD (Z=-1.535, p=0.125) and for HDD vs HUD (Z=-1.551, p=.121) [Table 5.3.28].

The graphics on the display are clearly visible

Condition	Mean Rank
HUD	2.75
HDD	1.61
HMD	1.64

Table 5.3.29: Ranks

N	18
Chi-Square	18.542
df	2
Asymp. Sig.	.000

Table 5.3.30: Friedman Test Statistics

Analysis usinng Friedman test shows a significant result of $\chi2(2)$=18.542, p=.000 (p<0.05). Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$ [Table 5.3.30].

Value	HDD-Windsh.	HMD-HDD	HMD-Windsh.
Z	-3.221[b]	-.108[b]	-3.375[b]
Asymp. Sig (2-tailed)	.001	.914	.001

Table 5.3.31: Wilcoxon Signed Ranks Test
b. Based on positive ranks.

There was a statistically significant difference in visibility of graphics for HDD vs HUD(Z = -3.221, p = 0.001) and for HMD vs HUD (Z=-3.375, p=0.001). However there was no significant findings in visibility of graphics for HMD vs. HDD (Z=-.108, p=.914) [Table 5.3.31].

The surroundings are clearly visible while using this display

Condition	Mean Rank
HUD	2.28
HDD	2.06
HMD	1.67

Table 5.3.32: Ranks

N	18
Chi-Square	4.429
df	2
Asymp. Sig.	.109

Table 5.3.33: Friedman Test Statistics

Analysis usinng Friedman test shows a non-significant result of $\chi 2(2)=4.429$, p=.109 (p>0.05).

Condition	Mean Rank
HUD	2.56
HDD	1.89
HMD	1.56

Table 5.3.34: Ranks

N	18
Chi-Square	11.586
df	2
Asymp. Sig.	.003

Table 5.3.35: Friedman Test Statistics

The interface in the display helped me to navigate properly

Analysis usinng Friedman test shows a significant result of $\chi2(2)=11.586$, $p=.003$ ($p<0.05$). Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$ [Table 5.3.35].

Value	HDD-Windsh.	HMD-HDD	HMD-Windsh.
Z	-2.244[b]	-1.664[b]	-3.220[b]
Asymp. Sig (2-tailed)	.025	.096	.001

Table 5.3.36: Wilcoxon Signed Ranks Test
b. Based on positive ranks.

There was a statistically significant difference in ranking for interfaces in HMD vs HUD ($Z=-3.220$, $p=0.001$). However there was no significant findings in ranking for interfaces for HMD vs. HDD ($Z=-1.664$, $p=.096$) and HDD vs HUD($Z = -2.244$, $p = 0.025$) [Table 5.3.36].

Condition	Mean Rank
HUD	1.36
HDD	2.14
HMD	2.50

Table 5.3.37: Ranks

N	18
Chi-Square	12.366
df	2
Asymp. Sig.	.002

Table 5.3.38: Friedman Test Statistics

Overall Ranking based on Preference

Analysis using Friedman test shows a significant result of $\chi2(2)=12.366$, p=.002 ($p<0.05$). Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$ [Table 5.3.38].

Value	Windsh.-HDD	HMD-HDD	Windsh.-HMD
Z	-2.500[b]	-1.380[c]	-2.982[b]
Asymp. Sig (2-tailed)	.012	.167	.003

Table 5.3.39: Wilcoxon Signed Ranks Test
b. Based on positive ranks.
c. Based on negative ranks.

There was a statistically significant difference in overall ranking of HUD vs HMD(Z = -2.982, p = 0.003) and for HUD vs HDD (Z=-2.500, p=0.012). However there was no significant findings in overall ranking for HMD vs. HDD (Z=-1.380, p=.012) [Table 5.3.39].

Quantitative Measures Summary

Based on these results, the HUD scores the best on most of the questions of the questionnaire as well as the application based quantitative measurements. Based on the user preferences as obtained from the questionnaire, the HDD ranks above the HMD though analysis of quantitative measures based on the application have mixed results in the case of HDD and HMD.

5.3.3 Qualitative Measures: Questionnaire

Subjects were asked to write comments on the different test conditions in a section of the questionnaire. They were asked to comment on what they liked and disliked about each condition. They were asked for any comments for changes that could modify or add to the display. They were also asked to give the reason for their overall rating between each condition.

What did you LIKE about this AR Display?

For HUD, some of the advantages and positive traits pointed out by the subjects were:

- It is simple and easily visible
- Interface is in the line of sight so there is no need to focus on it separately.
- Easy to see the real world.
- It doesn't move with my line of sight, I can chose to look away when I wish.

For HMD, some of the advantages and positive traits pointed out by the subjects were:

- Easy to see speed even when my head is not looking forward.
- Easy to notice warning messages.
- Does not require me to look back at the road to notice directions.

For HDD, some of the advantages and positive traits pointed out were:

- The device is familiar to use.
- It is fixed and doesn't follow my head.
- Out of the way and easier to see the surroundings.
- Clear and easy to see.

What did you DISLIKE about this AR Display?

For HUD, the disadvantages of the display based on feedback from subjects were:

- A little hard to see the surroundings.
- The interface was a little hard to follow at times.

For HMD, the disadvantages of the display based on feedback from subjects were:

- The position of the display is annoying.
- Difficult to focus on the display and the real world at the same time.
- The display moving around is disorienting and confusing.
- The display was in my face.

For HDD, the disadvantages of the display based on feedback from subjects were:

- Required me to look down and take my eyes off the road.
- I don't notice the change in speed always.
- Conflict with the rear view mirror where I was confused where to look.
- The display was too small.

What is the reason for the ranking?

This section tries to summarize the qualitative feedback provided by the subjects to explain their order of ranking each condition (1-Highest and 3-Lowest).

The main reason for HUD being rated the highest was of the display being in the field of view of the subject so that the subject did not have to move their eye and focus separately on the interface.

For HDD being rated most commonly at rank 2, the justification for being lower than HUD was mainly because it requires the subject to look off the road; It was however rated higher than HMD on average as it was the same system that users were already comfortable with.

For HMD being rated the lowest, based on feedback from users, the main reason was the position of the display at the top right position which forces people to focus on and off each time they look at it and glance back on the road.

5.4 Conclusions

The results show an overall better performance when using the HUD. Following the application based quantitative data, the relative number of navigational errors when using the HUD HUD was significantly lower when compared with both the HMD and the fixed HDD. This was also supported by the data from the questionnaire. The relative number of errors made while using the fixed console HDD was also significantly lower than while using the HMD. Since there was a significant difference in navigational errors when using the AR displays, null Hypothesis 1 (H1) has to be rejected.

Post analysis of quantitative feedback show that for the case of the number of times the user has crossed the speed limit, there was a significant reduction in the case of HUD when compared to the fixed console HDD. There was also a significant advantage for HMD for the same when compared against the HDD. This was the same as in the case of the time the subject spent above the speed limit using each display (HUD wins over HDD and HMD wins over HDD).

In the case of number of character models found while driving, there was a clear statistical significance for the HUD over the HDD. There was no statistically significant advantage for the HMD over the HDD. This was supported by the fact that HUD wins statistically over the other two AR displays based on answers from the questionnaire on being the best to maintain speed, navigate and drive safely.

It is clear that the overall driving of a user is affected by the type of AR Display that they use since there is significant data that differentiates the times they exceed the speed limit, the time they stay above the speed limit and how much they notice objects around them. Thus the null Hypothesis 2 (H2) has been rejected.

The next chapter talks about the results in more detail and also presents the conclusions from this study.

6
Discussion

THIS CHAPTER DISCUSSES THE results obtained from the user study and presents lessons learned.

In the case of navigational errors, there was an overall better performance while using the HUD over the other two displays. This may be due to the fact that the windshield is always in the clear field of view of the user while they are looking through it and there is no requirement to glance away from the road (as in the HDD) or to change focus (as in the HMD). Also showing the instructions in a manner that the user can keep them relative to themselves helps easy translation into real world . This was specified in some of the feedback provided by the subjects in the questionnaire, for example one subject mentioned that the interface is in the line of sight so there is no need to focus on it separately.

It is also interesting to note that there was statistically significant reduction in number of errors when using the HDD over the HMD despite the console-based AR Lens requiring the user to look down and away from the road. This may be due to the fact that having the display following the head orientation of the user might cause them to get confused since the instructions shown on the display were fixed with relative to the car. The instructions were based on car position and not head orientation position. This reasoning is supported by some of the qualitative feedback given during the user test where the user complained about the moving display being annoying/confusing. Few subjects mentioned a disadvantage of the HMD as being disorienting and confusing since the display follows their head movement. Instructions were provided based on car position and not head orientation position based on the findings of a pilot test by a colleague in the HITLab NZ for indoor navigation in storehouses by forklifts using AR Technology. Based on the pilot studies, users preferred arrows that were fixed relative to the vehicle rather than the head orientation.

Despite being statistically better than the HMD at avoiding navigational errors, the HDD falls short at both the number of times it exceeded the speed limit and the time spent above the speed limit. This is probably because the HDD is not in the direct field of view of the driver. The driver has to glance off the road and look at the console to notice changes, which is not the case for the HMD and HUD, both of which perform significantly better in this aspect. Feedback from the users also mentioned how hard it was to notice warnings on the HDD, which was also identified as an advantage for the other two displays.

In order to test how much the display forces the user to take his or her eyes off the road and become unaware of his immediate surroundings, character models were added at places along the map. The HUD clearly wins over the HDD in this case, which could be explained by the premise that the user is busy with his or her eyes off the road and does not notice the models in the surroundings. There was no statistical significance for the HMD over the HDD, which is a display that does not require the user to look away from the road.

This study shows clear evidence that navigation and overall driving of a vehicle is affected by using different AR Displays. The HUD was clearly superior over the HDD and the HMD and won in most of the measures. The HMD showed comparatively better results than the HDD in maintaining the speed limit but was the least preferred by most of the participants (Both null hypotheses are rejected).

6.1 Limitations

This section explains some of the limitations that the study faced. Some of these could be addressed in a future study.

- For the HMD, the navigational instructions were not provided based on relative position of the head orientation. The instructions were provided based on position of the car. This was done based on findings from a pilot study done on a similar topic at the HITLab NZ by a colleague.
- The size of the display areas for each AR Display condition is taken as the same. This limitation could impact the results for the Windshield HUD where a much larger display area could be used. This impact would also affect HMDs that have a wider field of view.
- The AR Displays were simulated in a VR environment for this this study. Using data from this study to model actual working AR Displays would provide interesting results. It would also add insight to how testing AR simulations in a VR environment would compare to real world tests.
- In the case of the HMD simulation, a non-stereo display similar to the Google Glass was picked, it would be interesting to study if HMD fares any better if stereo HMD displays were used.
- For the city VR simulation, there was no traffic added due to time constraints. Conducting the same tests with added load of keeping an eye on the traffic and collision avoidance would provide stronger results.

- The interface layout for each display is the same. Changing the layout of the interface based on the display may affect the outcome of the results. A common layout is used in order to prevent bias on results based on the layout.

7

Conclusion and Future Work

The major limitations of this study and the scope for future work that can be done based on its findings are explained in this chapter.

7.1 Future Work

This research has explored some aspects of the effect of different AR displays on navigation. However there are many future areas of research that could be explored. This section discusses some of the possibilities for future work in this area and also how future technology that may prove to be useful in this area of research.

This study did not explore all of the different interface options that can be used for each display. The Windshield HUD won over the other AR Display condition in this user study, and there is some existing research on the different interface options for HUD navigation that could be explored in the future. For example, the Ghost Car Feature [10], using on-road virtual arrows, projected line directions, etc. It will be interesting to see how these options compared against the other interface designs. It would also be interesting to study use of the entire windshield by the HUD as this could reduce the problem of the AR information displayed blocking crucial data about the surroundings based on where data is displayed on the windshield.

Much of the criticism for the HMD in this study is based on the design of the Google Glass HMD, with the display area being positioned in the top-right corner of the user's field of view, which is in their peripheral vision. With the recent advancements in the field of HMDs, there are many other display options that would be good to explore. For example, using stereo HMDs like the Hololens, could reduce the disadvantages of using a monocular HMD. If would be good to study how a stereo HMD would compare against the Windshield AR Display and the HDD tested in this study. As mentioned in the limitations section, another possibility for study would be if the HMD would provide navigational instructions relative to the orientation of the head.

One interesting field of study would be to add haptic/audio warnings when the user has to divert his attention to the Head Down Display. Using the traditional console based AR display (AR Lens) produced fewer number navigational errors than the HMD despite being a Head Down Display, although there were more made than with the Windshield Display. Maintaining speed and detection of objects in the immediate surrounding was where the HDD performed poorly. A combination of visual, haptic and audio technologies might provide a system that could compete with the Windshield AR Display. The impact of a different interface for the AR Lens would also be an interesting subject for study.

A future prospect for this study would be to test the actual AR Displays in a driving simulator based on findings from this study. Based on its feasibility, the study could be extended to testing on vehicles in real world scenarios.

7.2 Conclusion

Based on the results of the study, it was found that the Windshield based AR HUD was superior over the fixed console based HDD (AR Lens) and the Head Mounted Display. The HUD performed superior to the other displays in terms of ratio of number of navigational errors, maintaining the speed limit and ability to detect objects in the surrounding. It was also preferred by the subjects over the other displays. One of its biggest strength mentioned by the subjects was the ability to access information easily without having to change their focus or gaze.

The HDD performed relatively average in the test study and performed higher than the HMD for most of the tests. One advantage mentioned about the HDD was that it did not clutter or block any part of the subjects view. This allowed the user to glance at the instructions only when they need to. This was also mentioned as a disadvantage by some subjects as they needed to take their eyes off the road. For the measure of character models, even though there was no significant difference between the HMD and the HDD, it approaches significance. Further tests would provide stronger proof.

Even though the HMD showed comparatively better results than the HDD in maintaining the speed limit, it was the least preferred by most of the participants. It also performed poorly in many of the tests. One of the biggest shortcomings of the HMD as pointed out by the test subjects was that having the display move along with the user's head movement was confusing and distracting.

A
Appendix

Human Interface Technology Laboratory New Zealand

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HITLabNZ

INFORMATION SHEET

RESEARCH STUDY: A comparative study of using Augmented Reality interfaces for vehicle navigation

RESEARCHERS: Richie Jose, Christoph Bartneck, Gun Lee, and Mark Billinghurst.

INTRODUCTION

You are invited to take part in a game design research study. Before you decide to be part of this study, you need to understand the risks and benefits. This consent form provides information about the research study. A staff member will be available to answer your questions and provide further explanations. If you agree to take part in the research study, you will be asked to sign to this consent form.

PURPOSE

The purpose of this study is to compare different displays for vehicle navigation using Augmented Reality.

PROCEDURE

The study will follow the procedure outlined as below:

1. The participant reads and signs the informed consent form.

2. The participant answers to a questionnaire on demographic information and his/her previous experience with driving, playing games and using an Occulus Rift.

3. The researcher explains the study setup and experimental tasks for the participant to perform during the study.

4. The participant performs the experimental tasks including:

   - Using the Occulus Rift and a steering wheel to drive through a virtual environment following instructions displayed on respective display to be tested. The participant will also be required to look around for a specific object and keep to below the speed limit as they navigate through the environment.
   - Rating the usability of the display by answering a questionnaire.

   * While driving through the virtual environment, the participant's navigational errors are recorded.
   * The participant will repeat the tasks above for each display to be tested (3 in total).

5. The participant gets interviewed by the researcher on overall experience and feedback

The whole procedure will take approximately 40 minutes.

RISKS/DISCOMFORTS

Risks are minimal in this study. You will be asked to drive through a virtual environment by following instructions using simulation by the Occulus Rift. The discomfort felt by using the Occulus Rift will be minimal as each iteration will last around 5 minutes and is followed by a break.

CONFIDENTIALITY

All data obtained from participants will be kept confidential. In publications (e.g. Thesis, a public document which will be available through the UC Library), we will mainly report the results in an aggregate format: reporting only combined results and never reporting individual ones. In case of reporting quotes of the participants from the interviews, we will keep the source anonymous. All recordings will be concealed, and no one other than the researchers will have access to them. The data will be kept securely for a minimum period of 5 years and will be destroyed after completion of the research project.

PARTICIPATION

Participation in this research study is completely voluntary. You have the right to withdraw at anytime or refuse to participate entirely.

COMPENSATION

Upon completion of participation in the study, the participant will receive a $5 gift voucher based on performance.

APPROVAL OF THIS STUDY

This study has been reviewed and approved by the Human Interface Technology (HIT Lab NZ) and the University of Canterbury Human Ethics Committee Low Risk Approval process.

QUESTIONS

If you have questions regarding this study, please contact the researchers at the HIT Lab NZ:
Richie Jose (richie.jose@pg.canterbury.ac.nz)
Dr. Christoph Bartneck (christoph.bartneck@canterbury.ac.nz)
Dr. Gun Lee (gun.lee@canterbury.ac.nz)
Prof. Mark Billinghurst (mark.billinghurst@canterbury.ac.nz)

Please take this information sheet with you when you leave.

Human Interface Technology Laboratory New Zealand

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HITLabNZ

PARTICIPANT CONSENT FORM

RESEARCH STUDY: A comparative study of using Augmented Reality interfaces for vehicle navigation

RESEARCHERS: Richie Jose, Christoph Bartneck, Gun Lee, and Mark Billinghurst.

SUPERVISORS: Prof. Mark Billinghurst (mark.billinghurst@canterbury.ac.nz), Dr. Gun Lee (gun.lee@canterbury.ac.nz), Dr. Christoph Bartneck (christoph.bartneck@canterbury.ac.nz).

I have been given a full explanation of this project and have had the opportunity to ask questions. I understand what is required of me if I agree to take part in the research.

I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.

I understand that any information or opinions I provide will be kept confidential to the researcher and the administrators of the research project and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library

I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.

I understand the risks associated with taking part and how they will be managed.

I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.

I understand that I can contact the researchers or supervisors listed above for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human- ethics@canterbury.ac.nz)

By signing below, I agree to participate in this research project, and I authorize recordings or other materials taken from this study used for scientific purposes, and I consent to publication of the results of the study.

______________________________ __________________ _________

Participant (Print name) Signature Date

HITLabNZ
Human Interface Technology Laboratory New Zealand
www.hitlabnz.org

Feedback

Please take a few minutes to fill out this feedback form

Do you wear glasses?

☐ Yes ☐ No

What is your age?

____

How long have you been driving?

____

Have you used an Occulus Rift before?

____

I drive quite often.

Totally disagree						Totally agree
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

I have experience with driving games

Totally disagree						Totally agree
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

Please rank each display based on your preference (1: best ~ 3: worst)?

Google Glass ____ AR Lens ____ Windshield Display ____

Any other feedback? (e.g. reason of your ranking)

___

___

___

-Thank you! -

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Feedback on each wearable display

Please take a few minutes to fill out this feedback form for the wearable display you just tried.

Which display did you use?

Google Glass ____ AR Lens ____ Windshield Display ____

The surroundings were clearly visible while using the display.

Totally disagree						Totally agree
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

The graphics on the display are clearly visible.

Totally disagree						Totally agree
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

Using this display distracted me from driving

Totally disagree						Totally agree
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

It was easy to navigate using the display

Totally disagree						Totally agree
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

This display helps me in multitasking between maintaining ideal speed, looking around, and navigation

Totally disagree						Totally agree
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

The user interface of the display was useful in helping me navigate properly

Totally disagree						Totally agree
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

What did you LIKE about this display?

What did you DISLIKE about this display?

What feature would you like to CHANGE or ADD to this display?

I would feel comfortable if asked to wear this AR display on a regular basis when I drive

Totally disagree						Totally agree
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

- Thank you! -

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