Automotive Head-Up Displays
- Designing the user interface

Mikael Knöös & Magnus Wihlborg

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Mikael Knöös, ic06mk0@student.lth.se
Magnus Wihlborg, ic06mw3@student.lth.se

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Abstract

The evolution of Head-Up Display (HUD) usage have exploded and nowadays almost every car company has a HUD as an add-on. From the beginning they were only used to show the velocity, but now they have increasingly more information; navigation, tachometer, traffic signs etc. This paper takes a look a few years ahead and sees what we could use HUD for in the future. We could use it more like a display and not just lighting up static icons. We want to analyze and see what can be done with colors and animations. Too aid us in our work we built a car simulator with a windscreen and projected our UI (User Interface) onto this. Our research revealed that you need to think twice when designing and think about that you need to have a variable information amount and usage of animations dependent on context and location, using symbols above text, use the locality rule combined with color coding and not to use any unnecessary pixels.

Abstract

Användandet av Head-Up Displayer (HUD) har bokstavligen exploderat och nästan varje biltillverkare har HUD som ett möjligt tillval i deras bilar. I början visade HUD:arna bara hastighet, men nu har de även börjat visa annan information såsom navigation, varvräknare och trafikskyltar etc. Vårt arbete blickar in ett par år i framtiden och ser hur HUD:ar kan tänkas se ut då. Vi kommer att kunna använda dem mer som vanliga displayer och inte bara för att lysa upp statiska ikoner. Vi vill analysera och se vad som kan göras ned färger och animationer. För att underlätta vårt projekt byggde vi en bilsimulator med en vindruta för att projicera vårt gränssnitt på. Det vi kom fram till var att man måste tänka två gånger när man designar och tänka på att det kommer att vara variabel mängd information och animationer borde vara beroende på kontext och var man är. Symboler skall användas över text och helst ska lokalitetsregeln användas tillsammans med färgkodning. Pixlar som inte bär någon information utan bara finns där för att gränssnittet ska se mer estetiskt tilltalande ut bör också undvikas eftersom hjärnan ändå kommer att behandla den information.

Acknowledgments

We would like to thank Michael Winberg, for technical support during our implementation, and Dan Gärdenfors, Marcus Ericsson, Staffan Lincoln, for help during our design phase, and Mattias Lewin for the input in the construction of the simulator hardware, and Christoffer Kopp, for valuable input in our design process and help during the simulator build, and Erik Bäckström, Kristian Sylwander, our supervisors at TAT, for guiding us through our project and finally Joakim Eriksson, our supervisor at Department of Design Sciences, Lund University.

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1 Introduction

The Head-Up Display(HUD) is an old invention, first used in fighter jets. Nowadays they show up in more and more applications, mainly different types of transportations as trains, boats and cars. With the technology slowly maturing the HUD is becoming more and more advanced and it's usage in cars has exploded, since we started this thesis there is almost a HUD in every new released car. So if you have no HUD, you have slipped behind. What we want to explore with our thesis is to look a few years ahead and look at what we can to do with HUD then. Going from the concept of the HUD as a simple display showing static images, icons, RPM and velocity. We want to see what could be done if we utilize the HUD more like a display. What can we do with animations and color? How does these choices impact the overall feel and when does it get distracting? How much animations(movement, color changes etc.) would call upon the drivers attention, but not to distract him of his main task?

The pro's and con's of HUD usage:
Pro:

- Information on the windshield
- No (or little in our case) refocusing of the eyes
- Eyes on the road, reaction time

Con:

- Hard to see in certain lighting conditions
- Drivers attention on HUD, distraction
- Perceptual tunneling, reduction of peripheral vision.
- Distance overestimation

We have structured this report in the following way; first we have a pre-study where we go over current HUD systems and the history of HUD's. We then go through related work, to see what has been done in the same area as ours and what they have concluded. We describe our testbed setup that we used for our thesis, the software used and how we built it. Then we describe our design process, all of our choices we made and the scenarios we chose to work from. We then go over our results from our research, more or less what we have discovered that we feel you should take in account when designing a HUD UI. We go over the conclusions of our result och discuss our work. Finally we propose future work that is needed both of our testbed setup, the next step that will take it from good to perfect, and our HUD design, if we go forward a couple of years and if we have better testbed how can we improve the UI.

2 Background

2.1 History

Using a HUD for aiding the driver is a very old idea. When it was introduced in fighter jets during the sixties, the idea of mounting them in other transportation systems arose. Already in the late sixties there were trials made with a number of experimental devices that was installed in to vehicles for evaluation purposes[1]. In the eighties a more wide spread interest in HUD's evolved. The problem was that you needed to create something smaller, cheaper and less heavy than the aircraft HUD, if you were to mount it in a car[1]. There was some needed advances in technology to make it possible to create a device, to mount in a car, with a benefit for the driver. Because even though the concept of HUD came from the aircraft, not that much of the technology used for the aircraft HUD could be used for the car and it would need to be based on some other technology.

In the late eighties Genaral Motors (GM) started shipping cars with HUDs. In these early versions of HUD's there was little information, the only thing that was projected was the speed in digital format, see figure 1.

Figure 1: The HUD of a Pontiac from 1994 [2]

2.2 What is on the market?

Today almost all brands of cars have a HUD either as standard equipment or optional equipment, but it seems like not much has happened in the years between the launch of HUDs in cars and today. Figure 2 shows a HUD from Citroën as of 2010. When we see the concept pictures nothing has happened.

In other areas of the market it seems like a little more has happened. SAABs new 9-5 model has made some improvements to their display, a little more information and some simple graphics has been added. The added information is tachometer gauge, parking brake icon and icon for shown whether or not the full beam light is on. See figure 3

The best looking and most graphically appealing HUD we found on today's

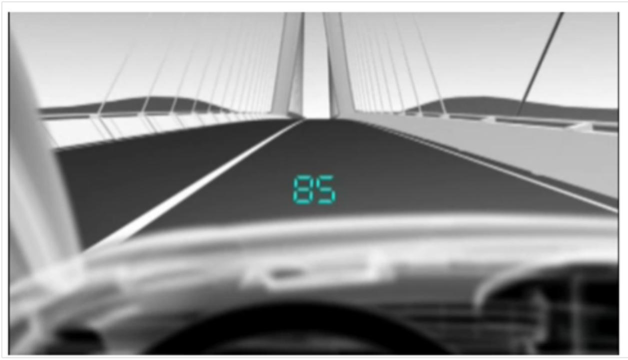

Figure 2: A concept picture from the Citroën HUD, 2010 [3]

Figure 3: SAAB 9-5 HUD [4]

market is BMW E60 model. BMW have placed the GPS information and the speedometer in the HUD. The quality of the projection is far smoother than the projection of the SAABs HUD. See figure 4

2.3 What is on the way?

What we have seen on the market is that the projection only cover a small area of the windshield and are monochrome. It seems like the technology has not developed at the same pace as in other areas, but then pioneer announced they have a full colored laser projector that will be released in 2012. One of the big benefits with the Pioneer projector is that the driver will be able to connect his or her android smart phone to it and the projector will act as the phones screen and you will be able to access for example the phones navigation application. Pioneer aims to launch this on the aftermarket. See figure 5

Figure 4: BMW E60 HUD [5]

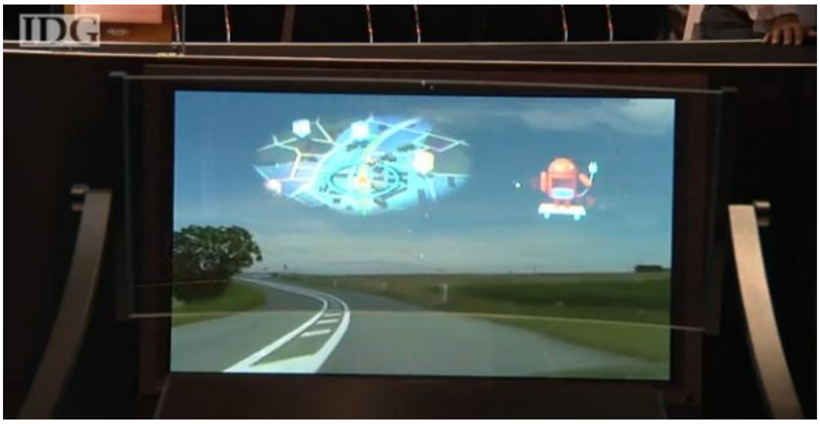

Figure 5: Pioneer full colored laser HUD [6]

2.4 Related Work

Head Up Display systems projects an image on to the windshield which partially reflects the image so that the driver can see the information. HUDs first appeared in fighter jets in the 1970s and a few years later they could also be found in low flying helicopter where information overload were a big issue for the pilot [7].

Today an overwhelming amount of human machine interfaces (HMI) can be found in all market segments of cars. Limitations in the driver environment space have burdened the dashboard area, which is distracting for the driver. The driver could easily get distracted from stimulus overload from the HMIs and this could result in a dangerous situation. These HMIs are so called Head Down Display (HDD) which might not convey a critical message to a driver when bombarded with different irrelevant information outlets [8]

The cars of today have a lot of different intelligent systems such as collision warning, pedestrian detection and brake warning and assistance. These systems are very good and help to save lives but it is unclear how reliable they are in making the driver aware of dangers lurking ahead when using ordinary head down displays [9].

One way to try to get the drivers attention to a specific warning could be to target multiple modalities i.e. haptic and audio cue. Haptical cues could be as simple as that the steering wheel starts to shake when the in-car systems wants the drivers attention. Auditory cues could be a voice that tells the driver what is wrong or what to expect on the road ahead. One drawback with auditory cues is that they are slow and takes time to process [9].

Through interpretation of sensors mounted on the car the HUD can increase the spatial awareness of the driver and decrease the response times in critically situations. The HUD is a complement to the HDD and research have shown that the decision making process should be evenly distributed between machine and driver [8]. The driver can easily get overloaded from stimulus and information, it is in these situations that the drivers perform poorly or don't follow the correct procedures and the HUD can help in the decision making process [8].

Why don't show the important information where the driver (hopefully) spends their time watching, in the car windshield. Research have shown that drivers respond 0.8-1.0s faster to warnings shown in the Head Up Display than they would if the warning was shown in a conventional display [9]. Drivers that have the information in the windshield gets a reduced amount of over speed warnings by 32% and reducing the time spent looking away from the road by 64% [9]. Driver inattention causes up to 78% of car crashes and 65% near crashes, a driver aid system should not produce driver inattention rather reduce it [10]. Visual clutter has been the major issue in previous HUD systems [11]. Appropriate placement, depth wise, is alleged to be all between 1.6 m to 5m. All different distances have their advantages [11].

The HUDs of today are static in the way that they only show the same information all the time for example speed, engine rpm and temperature. In A Novel Active Heads-Up Display for Driver Assistance they suggest a active display and by dynamic they mean that the display is adaptive it shows different kinds of information depending on the situation the car is in. In other terms context based information.

Showing an alert message to the driver could be placed in three different locations depending on the severity of the message. These three areas are where the eye has its focus areas. The area that has the sharpest focus is named fovea and the next where the eye has semi good focus is parafovea. Both could be found in the macula region and then there is the peripheral vision [9].

In a research project where they proposed three different ways to convey an over speed warning the most effective way is a warning sign in the peripheral vision

[9]. The other two ways were numbers and text and graphical version showing a vertical bar clearly showing the drivers speed and the speed limit. The graphical version of the system took longer time to decode for the subjects. If the driver is over the speed limit all of the graphics will start bouncing [9]. People testing the HUD system says that they did not have to look at the gauges as much as without the HUD system.

A major difficulty when designing interfaces in vehicles is creating an intuitive interface. What you don't want is a system that delays and that doesn't convey irrelevant information because it has an ineffective design. The onboard support systems should support the driver in the decision making process rather than constraining him/her [8]. Alphanumeric representation of data is slow to process and delays the reaction of the driver than what symbols do [8].

In a research project where the test subjects were supposed to follow a group of cars in bad weather conditions, the result of the project shows that when the drivers had the HUD they maintained a greater distance to the cars ahead of them and reacted much faster in other situations than drivers without the HUD [8].

The same study also showed that drivers using the HUD seemed to be relieved of some of the stress that occurs in dangerous situations while drivers without the HUD didn't, in both cases a heightened level of stress were detected [8]. This was also confirmed by the test subjects in interviews after the tests [8]. This study also showed that drivers with the HUD were more prone to drive faster in the bad weather conditions than they did with HDD; however they stayed under the speed limit [8]. Even though the drivers were keeping a higher average speed they were involved in far less crashes than drivers without the HUD [8].

Spatial cognition ability declines with age. Older adults have difficulty with cognitive mapping and way finding, the abilities to mentally represent a spatial environment and navigate efficiently in an environment. For example, research has found that the elderly have problems using "You are here" maps [12].

Smart GPS based navigation systems can aid the driver in difficult situations and therefore make the driver more confident in turning onto the correct road in intersections and complicated forked roads.

The navigation system adds complexity to the overall system. It creates an issue with divided attention and extra cognitive load with the problem translating the 2D overview map to 3D perspective correct environment. Even if today's technology has given endless possibilities of presenting information anywhere and at anytime, there is a gap/distance between the physical and virtual information space.

Depending of the relevance and the method of conveying the information and the user environment and circumstances the gap between the two spaces may shrink or increase. This gap is referred to cognitive distance [12].

There are two main components that cognitive distance consists of. First the cognitive effort required to go from physical to information space and locating the appropriate information. Second the effort to move back to the physical space and utilize and apply the gathered information. If the effort for any of these tasks grows the overall genitive distance grows. If a user switches between the two spaces frequently when performing a task the impact of cognitive distance increases. This also applies for people who have a cognitive difficulty or completing a time critical task.

The ability to respond simultaneously when performing multiple tasks is called decided attention and it is regarded as the highest level of attention. The larger cognitive distance the harder it is to have divided attention over information and physical space. If a uses fails to maintain divided attention it is common referred to split-attention effect. It often occurs when the same modality is used by the information and physical space. This proposes two important design questions that need to be addressed, what types of information should be in the information space and how should it be presented.

3 Interface Development Tools

During our thesis we have used tools to enable us to develop our UI. For C programming we utilized Microsoft Visual Studio 2005™and for Java we used Eclipse. When it comes to UI development we used TAT Cascades™, TAT MotionLab™and TAT Kastor™.

TAT Cascades™ is a UI framework, used when producing advanced UI. It seperates the application logic from it's appearance. It offers a wide range of UI controls and mechanisms for creating the best user experience in shorter development times.[13]

TAT MotionLab™ is an XML development environment for TAT Cascades™.[14]

TAT Kastor™ is the rendering platform. This is what powers TAT Cascades™ and it provides advanced UI layouting, animations, transitions, wipes etc...[15]

4 Simulator Setup

To be able to test our HUD design we decided to build a simulator. We bought car parts, a seat and a steering wheel at a scrapheap, a force feedback steering wheel and a ladder and a couple of particle boards to use as frame. The design of the simulator is very simple, use a long latter as a base, cut it up and bolt it together in a triangle shape for the mounting of the steering wheel and our windshield and have a flat surface to mount our seat. Because of the shape of the seat shapes we bolted to a piece of particle board and then mounted the particle board to the frame. We made a shelf to mount the force feedback wheel steering wheel and cut out the centre of the real steering wheel and mounted it on the outside for the force feedback wheel. With brackets we were able to mount the windshield. After some tests with a laptop in a real car we decided it would be enough for a HUD projector to use a standard TFT display and lay it down under the windshield to get a reflection in windshield.

Figure 6: Removing the car seat.

Figure 7: Trying out our idea of using a monitor for projecting our HUD.

In our pre-study we have seen many studies made with gaze tracking to evaluate where it is you focus your attention. And we felt that this would be a good

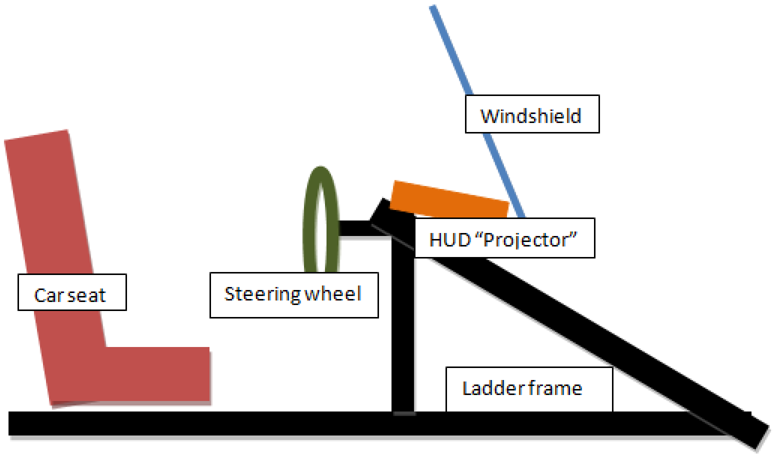

Figure 8: The idea of the simulator.

Figure 9: Building the simulator.

Figure 10: The finished product.

method to test out our HUD, to compare if the drivers focus was in majority on the road or not depending on the different HUD designs and going with an old-fashioned HDD. We tried a couple of open source solutions in our research phase. But we couldn't really get it to work properly and we wanted to start with our simulator build instead. And when we finished building our simulator we down prioritized it and started with our design work.

We realized that we would need two computers to run both the UI and the simulator software. Because we couldn't have one computer running two fullscreen 3D applications. And therefore we needed to send the telemetry data over the network. We tried a variety of different simulators but no one could really meet our needs with the possibility to get the telemetry data.

One of the simulators we tried was Driving Simulator 2009 because they had Lua scripting capabilities. Even though Astragon claims that their product called Driving Simulator 2009 had support for "External scene editing and possibilities for modding", this turned out not to be completely true. External scene editing was possible but the modding capabilities involved using different cars and creating your own missions. We tried luasocket, a network library for Lua, but we noticed that Driving Simulator had its own Lua interpreter and restricted the use of some libraries. We tried injecting our own dll's but we couldn't get their interpreter to accept them. Driving Simulator 2009 have AI cars that the computer handles which will help with the creation of real driving scenarios this is why we wanted to use it to start with and we tried to get in touch with Astragon with no luck. We tried to read the values from the steering wheel and pedals directly, the problem with this approach was that if we connected our program to the steering wheel and pedals the simulation software could not use it.

After failing with Driving Simulator we found a brute force way of doing it in Racer.nl were we could use the debug utility of the game, which prints different types of information into a file. The simulator generates a new file for every session of racing started. It posts the file name to a UPD port. We have a java server which listens to that UDP port and filters out everything but the filename and creates a file parser and starts reading this file. For every line of telemetry data it separates the different types of information and calculates the cars speed, we get the speed I in three variables; vx, vy, vz. We calculated the speed by, $\sqrt{vx^2 + vz^2}$ since we are not really interested in the vertical speed. When it has processed all the information we pass it to another thread which is running a server socket, and it sends the data to our computer which is running a server written in C. This server parses the stream and gets up in to the UI.

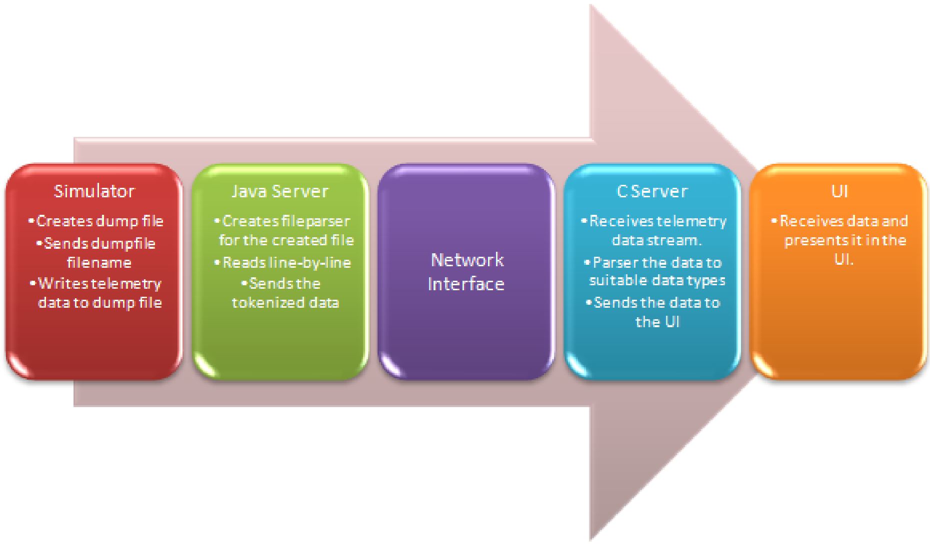

Figure 11: Test bed data flow.

If someone wants to change the simulator software, we have designed our telemetry extractor in a way that minimal code needs to be rewritten. We used the software design pattern named Template method[16], we chose this method because the information transmission process will not change depending on the simulator it is only the information extraction part that will change. This means that with template method we already have written the network part and the programmer that is going to write the telemetry parser only need to write the part that takes in the information and then send it to our network handling code.

With this said, there is no restriction in our software to use a different driving simulator than what we have used for this project. The restrictions lies in the simulation software itself and we had a hard time finding a simulator that allowed us to get information from the simulator.

One other option was to make our own simulator using a game engine such as Unity3D, Unreal Engine or Cry Engine. We chose not to follow this because even though a lot of coding is done the implementation of a car simulator with realistic physics and artificial intelligence would have taken too long time, but on the other hand we would have a simulator and scenarios that would have been tailor made for our simulator. This is left as a suggestion for future work.

We made a temporary solution to show the actual simulator projection, which consists of two tables stapled on top of each other and we put a projector on top that projects on the wall in front of the simulator. As our thesis progressed this solution became more permanent, because we felt that it was sufficient for our needs and we really didn't have the time to focus our attention on it, the only problem is that we have light contamination in the windshield, where we project the HUD.

4.1 Simulator Software

4.1.1 Driving Simulator 2009

Driving simulator is a simulation software that lets the player drive around a city. What differentiates this game from other games is that it is not built around trying to race as fast as possible between two points or around a track. The purpose is to drive around in a city and obeying the traffic laws. For example you must stop at a stop sign and you must use the turn signal if you are going to make a turn in the next crossing.

There are some missions that gives the driver or player some tasks to do mostly go to a certain point in the city or drive to several points in the city in a limited amount of time and still obeying all the traffic rules i.e. stop at red lights and staying below the speed limit.

One of the things that got us interested in using this game was the fact that it had artificial intelligence in the form of other cars occupying the streets in the city, which added a whole new dimension of realism to the simulation because situations that could arise in the reality cold very well arise in the simulation as well.

The feel of the game was not too realistic either the car felt very wobbly and one by accident crashed in to something for example a stop sign the sign withstood the whole force of the car that came crashing into it without breaking. Even worse was the fact that you ran the stop sign you would either loos the mission or get a warning depending on the mode you were playing but if you instead crashed into the sign nothing happened except that the car came to a sudden stop in front of the sign.

4.1.2 Racer.nl

Racer.nl was started as an open source racing game and that was what got us interested in this software because we could tweak the game to do what we wanted namely give us information about the car that we were driving in the simulator.

There are some drawbacks with this pice of software and that is that it is a racing game and that means that when we added AI cars these raced around the circuit at max speed all the time and this was not a realistic driving experience.

The circuit that came with the software was a "standard" racing circuit. We did however find a sub project to Racer.nl which did model a small city and it looked fairly good too but the problem with the AI cars were the same as described above. They did race around the city. We also experienced some problems with the frame rate at certain areas in the city.

When we tried to get a hold of the source for the latest version(0.8) to do our tweaking we realized that it was not released. The latest version of the source that was released was version 0.5 and when we tried that a lot had happened. We found the debug feature that was described before and that was when we decided to go with Racer.nl.

The decision to go with Racer.nl was the fact that we did feel that having real telemetry data and a realistic data fed in to the system this would enhance the reality feel of the whole simulator setup.

5 Design of the HUD interface

We used an iterative design process with small iterations, where we went from idea to prototype within a couple of hours. We interviewed a few people and asked them "If they could have any information in the windshield, what would that be?" most people answered that they did not know what information they wanted. The few that did know, wanted a police warning and calendar and schedule. These interviews were conducted in an unstructured way.

5.1 Scenario

Before we started with the interface development we created scenarios to get some context to what we were about to create, these are some basic ways we thought could show the benefits with a HUD.

5.1.1 Scenario 1 – Start up

In this scenario we wanted to create a graphically appealing start up sequence in the HUD, which shows the information from sensors placed in different parts of the car such as what the pressure in the wheels are and so on. Sadly though, this scenario never got past the drawing board due to some technical issues. The idea was to have a 3D model of a car spinning and coloring the areas where the sensors returned a correct value green and otherwise yellow or red depending on the severity of the deviation of the value.

5.1.2 Scenario 2 – There is an error in the car

What happens if the car runs low on fuel, or the water in the cooler runs dangerously low. How will the car respond and how do we convey this message to the driver.

5.1.3 Scenario 3 – Standing in a queue

When the driver is stuck in traffic what would be preferable to have as entertainment? Could the system prevent getting stuck in traffic?

5.1.4 Scenario 4 – Reversing

This scenario was actually added a while into the process because it was something that came up in one of our evaluation meetings we have had. Instead of having the old rearview mirrors could we instead use the HUD to give the driver all the information needed to reverse safely?

5.2 Personas

We created three personas to try to get ourselves in to the mindsets of how other people would perceive our interface. We will not go in to further detail as of how we have used them in the design process, more than that it was a nice tool to have when we got stuck in a design decision.

Name Olle

Age 55 years

Technical interest High

Income Middle/High

Note He wants the latest of everything, the biggest TV, the best surround system and the latest mobile phone. Money is not a problem.

Name Petra

Age 35 years

Technical interest Medium

Income High

Note She has a good job and a lot of money saved up. Design is more important than function for her. When it comes to high tech gadget she is of the opinion that they "should just work".

Name Albert

Age 25 years

Technical interest Extreme

Income Low

Note He uses almost all his money for different gadgets and he have chosen to lower his living standards to be able to have more money for technical gadgets.

5.3 Conceptual design

In the conceptual design we have chosen to focus on the visual part of the interface and not think anything of the interaction with the interface. We have not focused anything on safety besides not trying to distract the driver with animations and change in drivers the visual field.
Our interface can be split up in to two parts.

- Main interface
- Services

5.4 Main interface

The main interface as the name reveals is what you see in the car windshield. The design of gauges and warning icons we kept similar to the design of what you find in cars on the market today, on the other hand we have experimented with the design of gauges and icons that are in coherence with our services that are in the car.

When the driver is driving we have chosen to limit the use of text to the RPM meter and speedometer and used icons to convey the rest of the information. We used icons and symbols that a driver is already familiar with because an icon is much faster recognized and interpreted than what text is.

5.5 Services

The services that we have chosen to use are

- Facebook
- Twitter
- Spotify
- Mobile Phone
- GPS
- Rearview Camera
- Speed-sign recognition

There are no limit as to what and which systems might be implemented into cars but we have chosen to limit us to these seven for the sake of this prototype. We have restricted the use of these services to when the car is at a standstill except the Global Positioning System (GPS), rearview camera and Speed-sign recognition which can be seen when driving.

5.6 Concepts

In our first concept sketches we used the whole windshield which later turn out to be a tall order, we had to design in "portrait" since we used an ordinary LCD computer screen as the projector. We had plans to cluster three screens but this was easier said than done. The HUD only occupies the area right in front of the driver.

5.6.1 Lo-Fi concepts

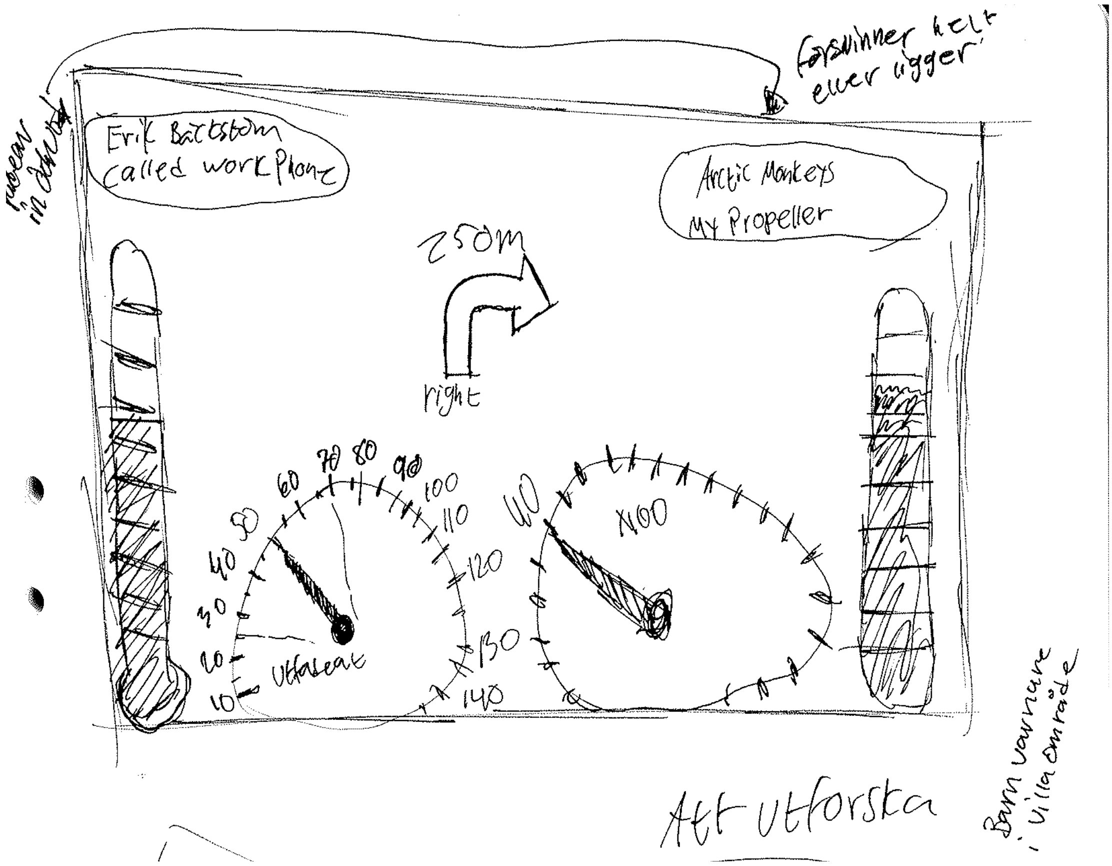

Figure 12: Our first Lo-Fi concept.

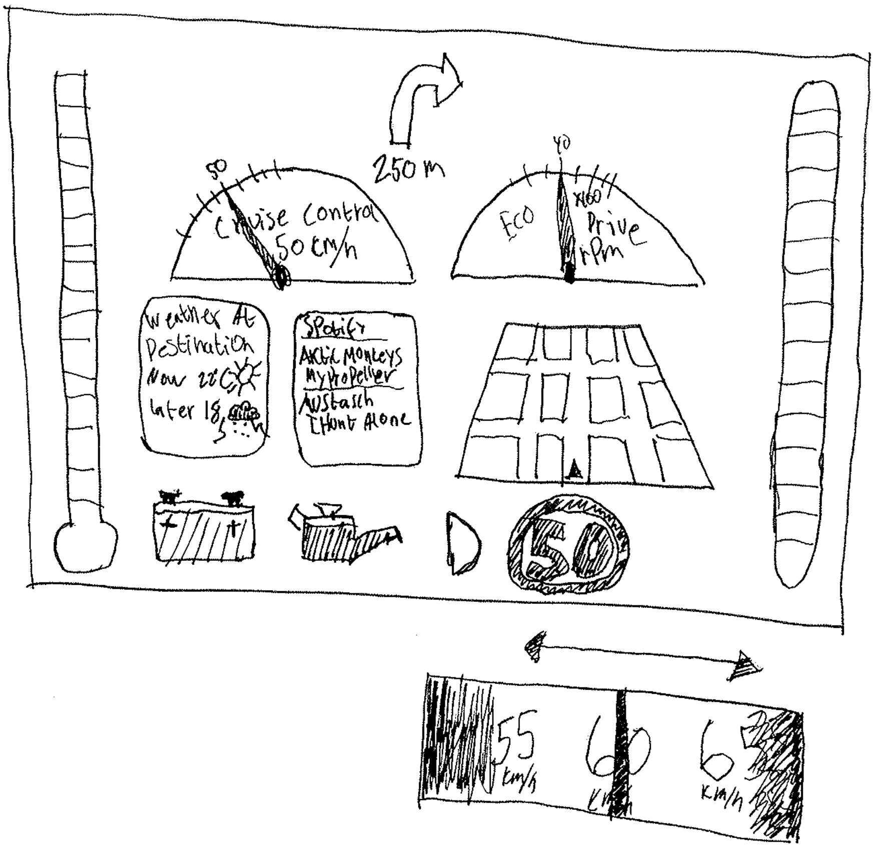

Figure 13: Our second Lo-Fi concept.

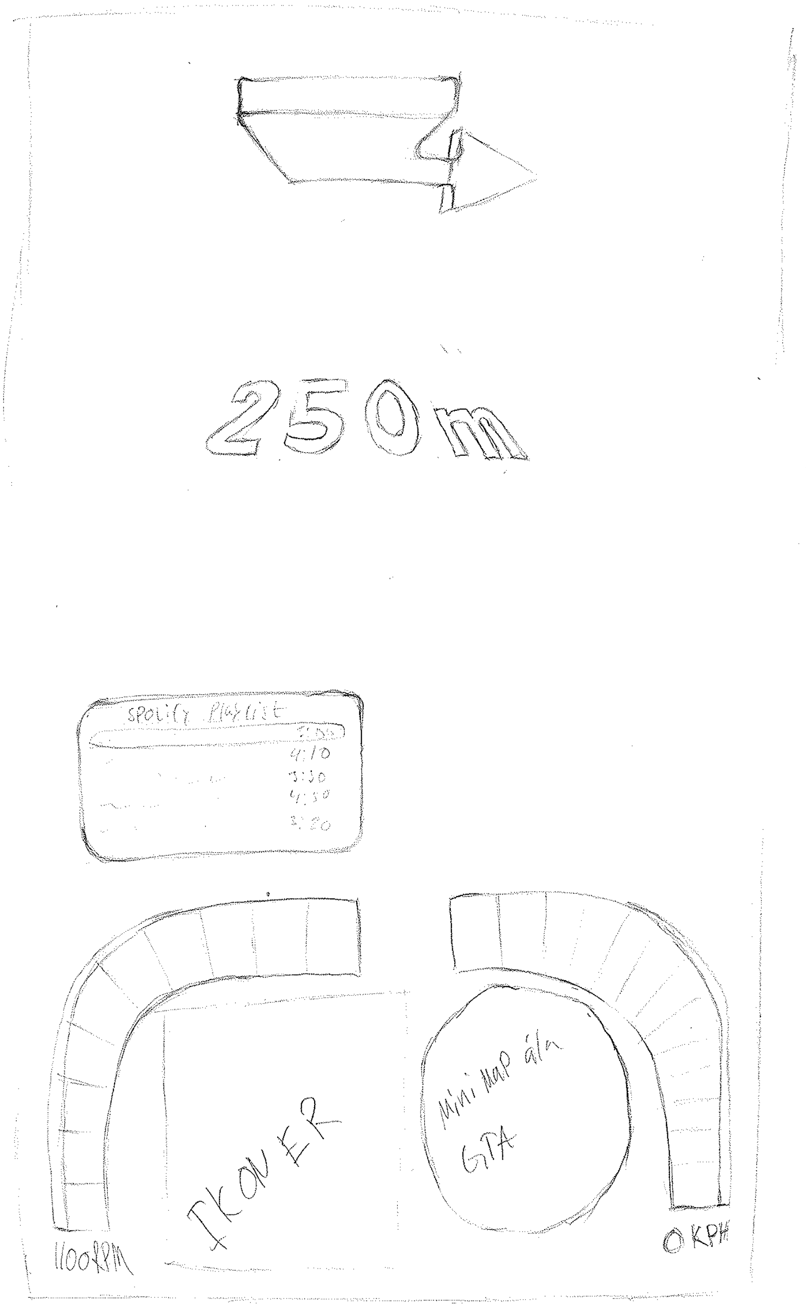

Figure 14: Our third Lo-Fi concept.

After the first concept we started designing some HI-FI prototypes since we did not know the dimensions of the projection. We have four interfaces which are almost the same but we have different looking gauges in them. The interfaces shown below are the standard interface that the driver sees while standing still and all of them are working fully in the simulator we have built. The black background will not project any light onto the windshield and therefore it will be transparent.

5.7 First analogue Hi-fi prototype

This is our first Hi-fi prototype; we tried to keep our interface simple, clean and not confusing. We chose to have analogue gauges because when we asked people they seemed to want to have the classic rotating needles. One man even went as far as claiming that he would not buy a car that did not have this type of gauges.

The white gauges in this interface does look good, but when projected on to the windshield it bothered the driver because of the white in the gauges. The map that is under the gauges does have the same problem but it is not as bothering here since it is not located right in the drivers visual field. In the middle of the interface the information about the gear is located. The driver can easily see which gear that the car is in and also see the two next and previous gears.

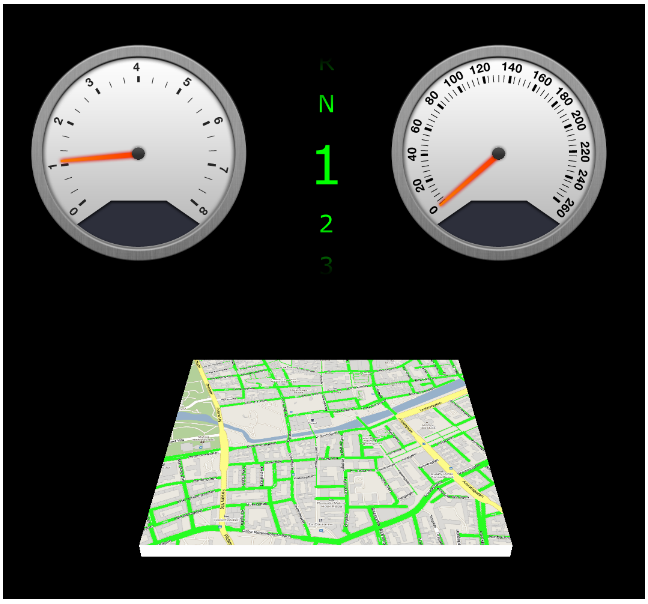

Figure 15: First analogue prototype.

5.8 Second analogue Hi-fi prototype

In this prototype we changed the gauges to have a black background which will make the gauges see through in the HUD. The interface felt less clogged up with these gauges, because now we did not have any white left in the gauges and the white areas in the gauges in 15 were contently processed by the driver and most important of all is that the white area does not convey any information at all.

If the reader looks closely on the gauges you notice that the area around the needle has a slightly brighter color, the reason for this is that we wanted to lead the eyes of the driver towards the current speed and RPM.

We also stripped down the gear widget and removed the next and previous gears with the motivation that if you are in for example gear 1 you know that the next gear is 2 and the previous gear is neutral. The only benefit of having the next and previous gear is that new drivers and if someone is borrowing your car they know the layout of the gearbox straight away.

When trying this interface we realized that what we had to apply the same design pattern to the map as we had applied to out gauges. At a closer look there is a lot of unnecessary information in the map. When driving the only information that is important is the roads and where you are, everything else is less important.

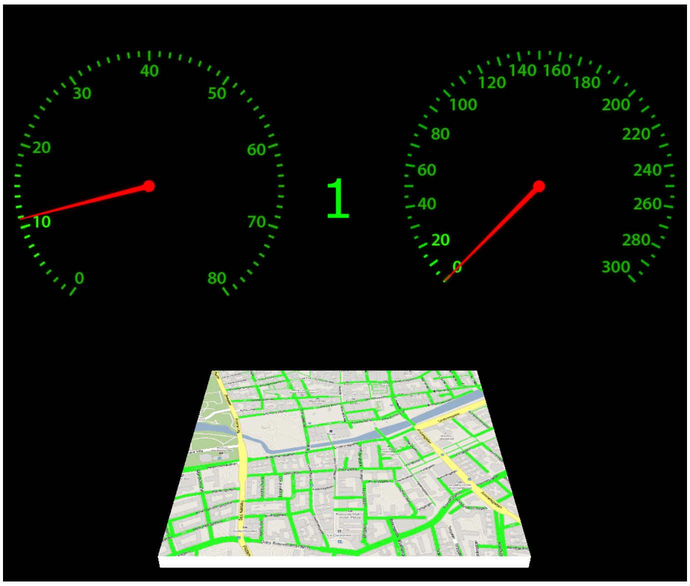

Figure 16: Second analogue prototype.

5.9 Digital Hi-fi prototype

We made a prototype where both gauges were completely analogue and used graphics to show what gear the driver is in. The graphical approach to showing the gear information was a good idea but it felt very bulky when tested in the simulator.

The RPM meter (the one that says 1100) is color coded, as the RPM increases the color changes from green to yellow and finally to red, this color transition is seamless. RPM information is incremented every hundred value.

Our speedometer in this prototype is made up by three rolls, numbered 0 through 9. They roll in to position to show the current speed, much like the analogue trip meter seen in slightly older cars. The design was not well received by the testers, their feedback was that when driving you almost never keep a constant speed. Most of the time you have an interval you stay within. These small changes, in speed, is highly noticeable when the speedometer increments and decrements and therefore can act as a distraction for the driver.

Since this information will be available in the drivers peripheral view this could increase the cognitive load and that is the opposite of what we want our HUD to become.

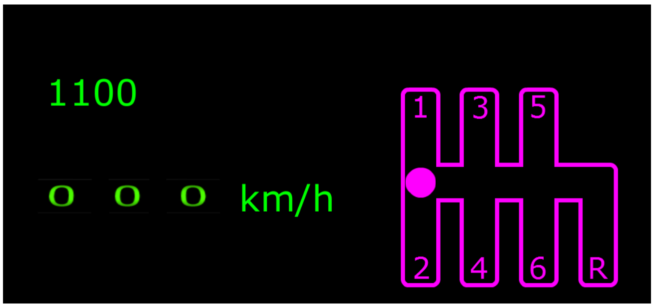

Figure 17: Digital prototype

5.10 Final Hi-Fi prototype

The biggest difference in this prototype and the other analogue prototypes is that we removed everything except the roads in the map. We decided to have a very dark gray almost black background on the map just to give the driver a hint that it is located on a tilted plane. Without the background, it was perceived, by some, as it was a wavy surface and not flat.

We moved the text in the gauges to the outside, because the text of that size we needed barely fit inside and was very cluttered. The RPM meter is color coded here as it is in many cars.

This is also how our final interface looks in the simulator we built at TAT Headquarters in Malmö.

5.11 Services

By services we mean other applications than the expected speedometer, RPM meter and such. The services we have chosen to include in our prototype are

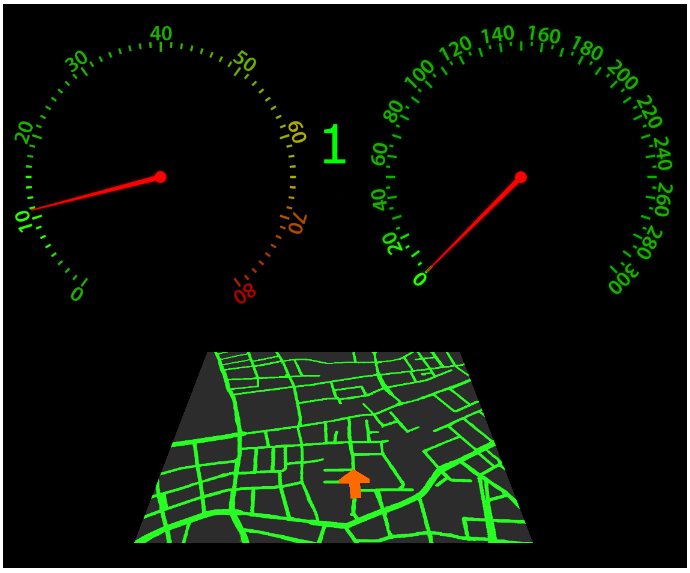

Figure 18: Third and final prototype

facebook, Twitter, Spotify, rearview camera, speed-sign recognition and GPS. We will in the following section describe our different concepts for the interfaces for these applications.

5.11.1 Global Positioning System

All mid- to high-end cars of today have a GPS system built into them. What we have done is moved the interface from a conventional dashboard display and instead given the driver this information right into his or hers view. All the parts of the GPS in our HUD are mock-ups, they are interactive but it is not real GPS data we interpret.

When we started out sketching on the interface for this service we started with the intention of only having a map at all times, as shown in the previous examples of our prototypes. After a few meetings and some input from people that have tested the prototype we changed it because the map even the stripped down version that is in the final prototype proved to be information overload for the driver. When the car is moving the driver is not interested in anything else than what road he or she is on and when they are supposed to make the next turn, but we did not want to leave the map concept completely. We made the GPS dependant on what and where the car is located instead.

If the car is traveling on a speed that is greater than 30 km/h then the map disappears and is replaced with GPS arrows, we made two prototypes of these arrows. The first arrows we made were simple arrows as the picture below shows.

When tested we discovered that these arrows do not have anything that actually says anything that a user should interpret these as GPS directions. After this

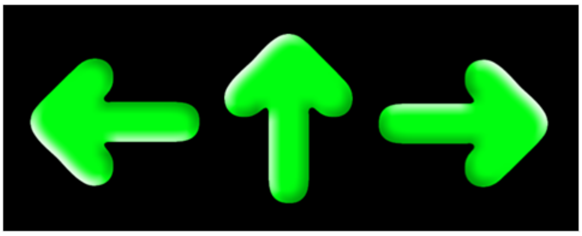

Figure 19: First draft of our GPS arrows.

we redesigned them to look more similar to how the streets look and the way that most GPS visualize their information today.

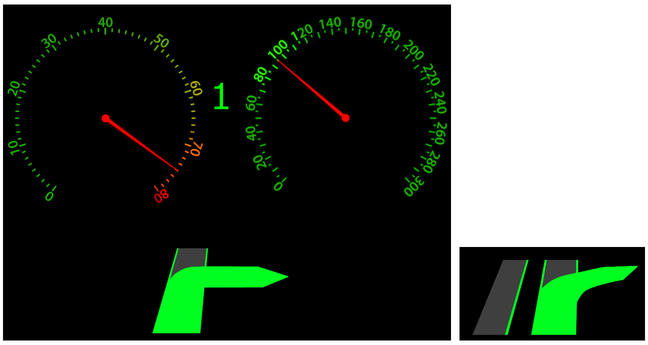

Figure 20: New GPS arrows, to the left city mode and on the right highway mode.

These arrows were better received by the people testing the interface; however we made one final tweaking of the highway version of the arrow. The lane where the cars are driving in the opposite direction can be seen in the image. After what we have learned from the case of the gauges, since this is not conveying any information we removed that part of the image to strip the interface of unnecessary pixels.

The map also has a few features which we have not brought up yet. When the car is at a standstill the driver is able to maximize the map view to fit almost the entire screen, we have chosen to keep the speedometer and RPM meter visible. The idea behind this is that we did not want the driver to feel that he or she navigated away from the main screen but rather just get a better view of the map.

As soon as the car starts rolling in any direction the map flips down again and driver will not be able to flip it up again until the car is at a complete standstill. The transition between the two states is animated so the speedometer and RPM meter looks like their pushed away by the map.

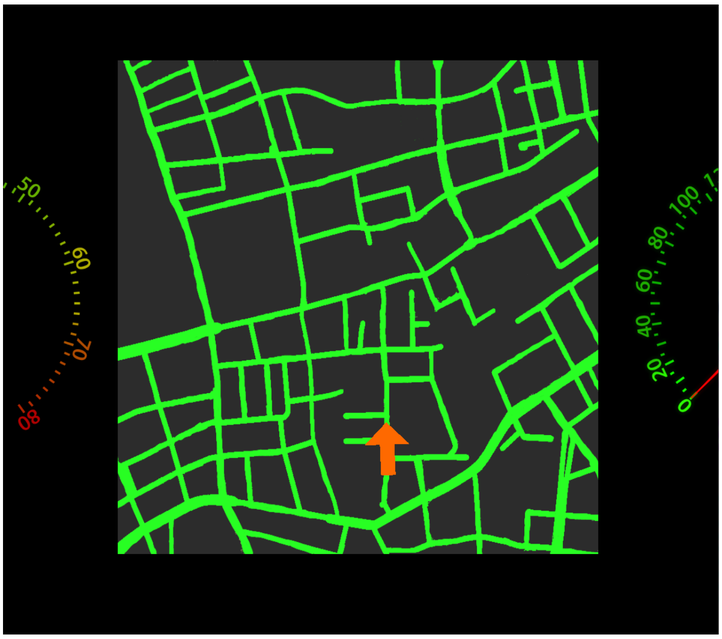

Figure 21: Map in its up flipped mode.

Another feature that we added is Points Of Interest (POI) which are shown by small cones that should resemble map needles as shown in the image below. The image shows the result of a search for a gas station for example.

Figure 22: Map with POI needles.

After the map was redesigned we let co-workers try the new design and ask them what they thought of the map. Most people liked it but there were one person that requested a way to see the traffic volume. We both thought that this feature would be good to have, after some brainstorming we came up with that the best solution for this feature would be to turn the map in to a heat map. A heat map is color coded image, in our case the colors goes from green through yellow to red, where green is no to low traffic yellow is medium traffic volume and red is high traffic volume. This feature can be activated even when driving. One of the benefits with this feature is that if the car GPS suggests a detour, the driver can access and get this traffic volume information and see that the shortest way may be overloaded and therefore know why his GPS redirects him all over town instead of the quickest route.

Figure 23: Heat map showing traffic volume.

5.11.2 Social Media

When designing the interface we wanted to have more unusual features than what could be found in cars today and pretty quickly we started thinking of different kinds of social media. Quickly we delimited us to only have facebook, twitter and Spotify. Spotify is a music streaming service which (currently) is only available in selected countries in Europe, this is not a social media per say but we choose to group it here.

We said earlier that we do not focus on the safety, but when it came to the social media we decided to limit the use of social media to when the car is at a standstill. The social media parts of the interface were designed parallel to the map interface, so the first draft of the design facebook were located on the backside of the map.

When the car was standing still and the drivers accessed facebook the map would raise up and flip 180 degrees and there we placed a screen shot of the facebook webpage. When the car starts to roll the same animation is played in reverse. We experimented a little with this transition, we let the screen shot drop down from the top of the screen.

Figure 24: First prototype

This approach was a good starting point but we soon realized that showing the webpage on the car HUD was not the right way to go. Looking a little bit closer on the web page you can see that there is a lot of unused space and nothing else did fit in the screen. We decided to extract the text feeds from the services and show these to the driver in specific content holders color coded to match the icon of the social feed.

The problem with these designs were as we did come up with earlier that facebook contain a lot of unnecessary pixels that just are not conveying any sort of information. We had to redesign it.

One of the features we really like in the android mobile phone interface is the drop down menu where all new messages and other feeds are collected. The idea behind this interface is that things that have occurred between the current time and the time before that are visible here, if nothing have happened this box is empty. When this box is accessed it is animated in from the top of the screen.

We made one final design because we were not satisfied with the android style design because we felt that this had already been done and wanted to come up with a new design that were completely our own.

In this prototype we used the law of closure to sort the information in to two areas, the top one that is the phone area and the lower one that is the feed from

Figure 25: Reworked social page

Figure 26: Android style drop down box.

facebook and twitter. We color coded the facebook and twitter feed to match their icons, otherwise we kept the interface simple and clean in order to make it quick to check the latest happenings.

When we did the transitions between the normal interface and this interface we tried to make it look like the interface is trying to follow the car so it flies in from behind and when the car is rolling it will look like the car is driving away from the interface. This transition is different from all the rest of the transitions because all other transitions are coming in from any of the sides where as this will emulate that it comes in from behind of the car.

Figure 27: The final design for the social page.

5.11.3 Rearview Camera

The rearview camera is simply a back facing camera mounted in the rear of the car. When the car is put into the reverse gear this view becomes visible. This feature was requested by one of the tester because in the area where he lives there are a lot of families with small children. He wanted a better way to make sure that there are no children behind his car when reversing out to the street.

The design of the rearview camera is an image from the back of the car placed in the screen right in front of the driver, and the animation is similar to that of the map. When the car is put in to the reverse gear the speedometer and RPM meter is animated out towards the edges of the screen and then the rearview camera is animated down from the top.

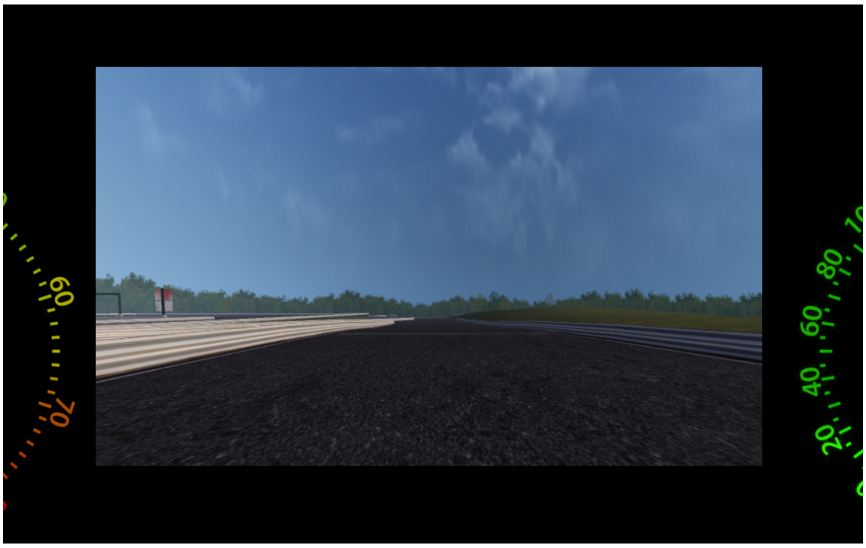

Figure 28: Rearview camera

5.11.4 Warnings

Warnings are an important part of the cars interface. We decided that we wanted the warning message icons to be impossible to miss.

When an error occurs it shows up in the HUD in a normal size, once the car is at a standstill the icon suddenly grows and pushes the speedometer and RPM meter to the sides as seen before. If the car the starts rolling again the icon its original size, or if the map is accessed the icon minimizes and stays on top of the map. The icon is always visible when there is something wrong with the car.

5.11.5 Speed-sign recognition

One requested feature, both by us and our test persons, is speed-sign recognition. They are becoming more and more comman as an add-on to todays cars. What we propose is a that the car reads the sign and a similar sign with the same speed lights up in the hud in the near vicinity of the speedometer. It will blink slowly two-three times and then be completely litt.

In the next genration HUD's we imagine that we will highlight the real sign next to the road, so that we see it even in low visibility conditions.

6 Result

The most obvious result this project has produced is the car simulator we built with a working HUD and a connection to simulator software and have in our office at TAT. The simulator is also expandable and with a little bit of work it

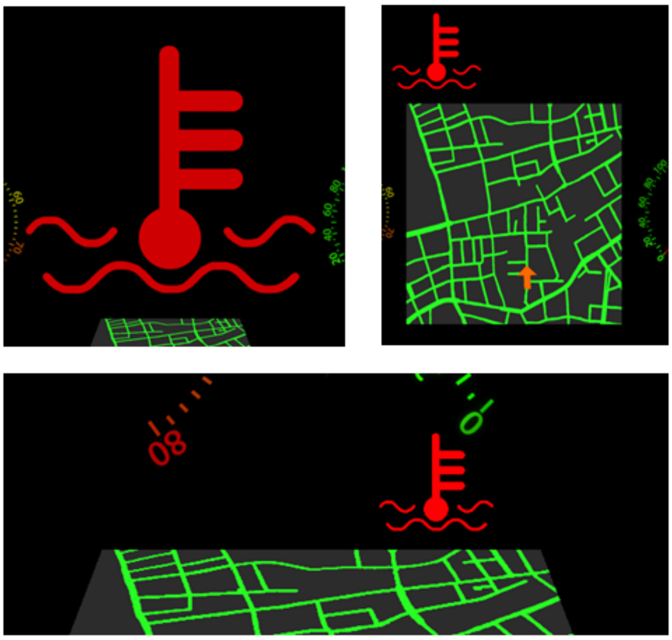

Figure 29: Warning messages in different states

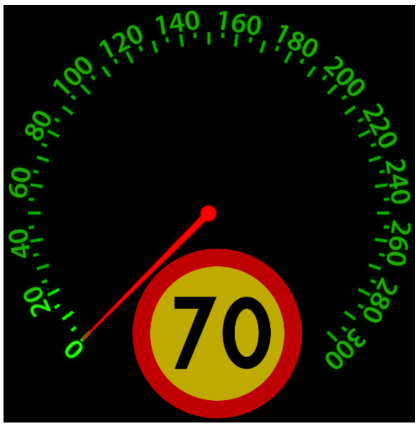

Figure 30: Speed-sign recognized.

could be augmented with a cluster display and other displays.

The second result produced by this project is a HUD interface which is bigger than any HUD seen on the market today, but because we have had some trouble with double reflection this cannot be used in an efficient way.

The result that we have come up with that is on the subject of this project, because it is a design project after all is a small set of tips of what to think about when designing a large HUD. The list below presents these and will be further described below.

1. Only use pixels that carry information
2. Information amount variable depending on context and location
3. Make the usage of animations variable depending on context and location
4. Use symbols before text
5. Use the locality rule together with color coding

6.1 Only use pixels that carry information

This suggestion has been brought up several times in this report but we cannot stress this enough, because the interface will be visible to the driver at all times having pixels that do not carry information will overload the driver information wise. This non information carrying pixels will be interpreted by the driver unconsciously and this could become uncomfortable if exposed for longer periods of time.

Aesthetically using pixels that do not carry information have a tendency to make the interface look clogged up and bulky. This problem was an even bigger problem in our setup because we did not have the interface projected at the right virtual distance from the windshield; this made the interface feel like it was more in the way rather than aiding us in our driving task.

6.2 Information amount variable depending on context and location

When deciding what information to have visible when we crafted something we called a information matrix. Some of the features are binary,either their on or off, and some other features are variable. See the matrix below.

6.3 Make the usage of animations variable depending on context and location

When the car is in motion the animations should be used with caution, too big animations will scare the driver and for a split second focus on what is happening in the windshield and not what is happening on the road. When in motion restrict the usage of animations so the message appear in a gentle way and consistent for the same types of messages the whole interface through.

If the car is at a standstill the amount of animation can be increased, but they should be able to stop them quickly if for instance the car is standing in a deadlock and the line suddenly starts to move, the animation should stop and the driver can focus on the driving task.

Function	**Highway/ Country road**	**City driving**	**Standstill**	**Reversing**	**Severe problems**
Gear	Normal	Normal	Normal	0	Hidden
RPM meter	Normal	Normal	Smaller	0	Hidden
Warning messages	1	1	Larger	1	1
Social media	0	0	1	0	0
Map	Zoomed out	Zoomed in	Large(Active choice)	0	Closes place to fix
Speedometer	Normal	Normal	Smaller	0	Hidden
Rearview camera	0	0	0	1	1 (if reversing)

Table 1: Context matrix

6.4 Use symbols before text

Use symbols before text because these are interpreted faster by the driver than text, and in a car which is moving the less time it take for the driver to get the message the better.

Think of an interface with a lot of different messages conveyed through text this will feel like a lot of information but when using icons instead the same messages will not make the screen feel as cluttered.

6.5 Use the locality rule together with color coding

Use the locality rule described in Gestalt psychology, which describes that objects located close to each other will be grouped together by the human brain, for example if a speed sign is read show this information in the vicinity of the speedometer.

Color coding parts of the interface will also make the driver group these together. Using a combination of locality rule and color coding will make this relationship stronger. Let us take the same example again the speed sign reading. If we place the information close to the speedometer and use the same color scheme as the real speed sign the driver is more likely to map the real speed sign together with the speed sign indicator located near the speedometer.

7 Heuristic Analysis of the UI

We will use the eight golden rules of interface design that Shneiderman formed which indicates how well an interface is designed[17].

7.1 Strive for consistency

We kept the overall look of the interface the same for most of the time. When for example all the warning icons have the same appearance and will behave in the same way.

7.2 Cater to universal usability

When we designed the interface we did this so that all drivers should be able to use the system with minimal or no manual reading. This is why we have chosen to stay with the analog gauges and use the same warning icons as can be found in cars today.

7.3 Offer informative feedback

All actions have feedback either through the system responds as expected or feedback that tells the driver that this action is not available now. This can be seen for example in the social part of the interface where if the car is at a standstill the correct interface will appear or if the car is rolling a facebook-ban sign will appear.

7.4 Design dialogs to yield closure

All dialogs in the interface have a clear transition; they have a start and a finish. When the transition have reach its end the user is in another part of the interface.

7.5 Prevent errors

As the interface is constructed today it is not able to make any errors, because for example if the driver tries to access the social page when driving the system will clearly show that this is not available at that moment.

7.6 Permit easy reversal of actions

Since we designed the interface to prevent errors the only error that can occur is that the driver navigates to the wrong part of the interface, this is easily reversed by navigating backwards to the starting point.

7.7 Support internal locus of control

The only time our interface does anything without a user input is when an error has occurred otherwise the interface will respond to what the driver is doing with the system.

7.8 Reduce short-term memory load

The interface does not require the driver to have anything in his or her short term-term memory because we keep everything stored in the interface, for example the GPS data is shown either as a map when standing still or driving slowly or regular GPS arrows otherwise. If an error occurs the icon will always be visible in the interface.

8 Future Work

8.1 Test bed

As mentioned in the description of our test bed setup, we have left some things undone because of the time it would take to fix it all. After all, the thesis is not building a perfect simulator but in fact the simulator is just tool needed to try out our UI. But we would like to go over the problems we think it has and what needed work it has. First of all we need to find a new way of showing the road, not using a projector whose light contaminates the HUD in windscreen. For this it would we perfect to use a back projection setup, using the same projector but stretching a cloth, made by some optimal fabric, and projecting on a mirror and from the mirror up on the back side of a cloth, that lets through the light and shows an image on the other side. An example of a setup of this kind was shown to us in the VR lab at IKDC.

To make it a more complete setup, one option is to mount a cluster monitor on the simulator and therefore make it possible to test out cluster designs also. This shouldn't be a problem by using the same mounting system as the HUD screen.

To get more image space to play around with when designing the HUD one could take advantage of multiple-screen rendering, use three screens instead of one and place them side by side and have a HUD that stretches over the width of the windscreens.

8.2 HUD design

Our design work has always circled around making a HUD design that would possible be out on the market in 2 – 5 years. The technology limitations that we have today, we see that we do not have in the near future. Since we wanted to be able to see our work in action, test it and get an overall feel of it, we were somewhat restricted.

In our test bed we only had one screen for projecting our UI to the windshield that was a certain size and our design was done with regard to this and so our HUD is only $1600 \times 1200(height \times width)$ pixels, still more than average HUD, but when the technology matures it will be bigger and bigger and GM is even researching usage of the whole windscreen with an AR approach [18]. This gives a new approach to designing, we made more of a futuristic design where we highlighted the road and used AR(Augmented Reality) for personalized traffic signs with your own points of interest.

One interesting investigation that could be done is to add a cluster to our simulator and by using eye and gaze tracking investigate the time of road contra time on road. From that data conclude if the HUD contributes to a safer driving environment rather that just being an "awesome add-on". Maybe you look at cluster just as much when driving with the HUD, can the design of the HUD make the driver be more prone to use the HUD over the cluster or vice-versa.

There is a lot more work in this area to be done, investigating the effects on safety the full AR screen has and where to place objects, would you make them very natural so they blend in more or unnatural to make them stand out.

It would be interesting to try to design new ways to show information about for example speed. In this report we have not experimented much at all, in our few low-fi prototypes we did do some sketches on how we would like to present speed and RPM data in different ways, through for example diagram or as seen in appendix A, we tried to make the gauges look like the gauges from a racing game.

9 Conclusion

9.1 Simulator

People from TAT: s automotive department told us that it was a big difference between sitting designing and testing at a desk than it was doing it with the simulator. Even just sitting in the simulator when it was turned off gave them different ideas. When we first tested our simulator we also came into a different mindset.

9.2 Interface

One of the biggest conclusions we came up with during the design of this interface was, if a pixel does not convey any information remove it, only show important information to the driver. If an interface has a lot of areas that are colored which does not have any information the interface will look more cluttered and this will increase the cognitive load of the driver.

Animations are good to get the drivers attention but when used in a wrong manner they can become dangerous. A variable amount of animations is the most preferable, when the car is standing still the animations does not have to be as subtle as when driving.

From the few testers who have tested our prototype they preferred to have a symbol based interface rather than an interface with text. This is also backed up by reports read in our pre study. Hence we suggest the continuing the usage of analog gauges in the HUD. Always use graphics to convey a message whenever possible.

The use of augmented reality to enhance drivers perception, for example highlight traffic signs. The emulation of traffic signs to convey feedback as the case with when trying to access facebook when driving then the system responds by showing a facebook icon with a cross over it, we tried to make it look like a facebook-ban sign.

The interface should always give the user feedback, especially if the operation the driver is trying to carry out is not allowed, otherwise the systems seems broken and it becomes an subject of unnecessary irritation.

We discovered that the projected image on the screen still is not as far away from the driver as we would want; this means that the driver still has to refocus his or her eyes when using our HUD. As a test bed for prototyping and first evaluations this does not matter. One of the main benefits of the HUD is that the driver eyes do not have to refocus. For this reason this simple setup would never work and for the fact that it is extremely sensitive to light pollution.

10 Discussion

If we get to the stage where we can use the HUD as replacement for the cluster, we can use the cluster space for something else or even perhaps empty space and through that get a more hospitable driving environment where the driver has a 100 percent focus on driving and nothing else.

With a HUD the driver can have a more relaxed pose when driving, because the driver does not have to look down at the dashboard because all the information he or she wants is in the windshield.

There are more cons than pros in the list brought up earlier in this report. We believe that some of these problems will be solved in the future. From what we have seen now is that the projectors that use laser to project their image they are more resistant to light pollution the same with the small size of the HUDs seen on the market today for example Pioneer have presented a new laser system that they are going to launch in 2012. Driver inattention is more prone to occur if the HUD interface is poorly designed.

It is worth discussing a little around having a full-blown augmented reality system in the windshield, this is a flattering thought but this feature but this could easily get out of hand and information overflow written all over it. We think that this feature would be very both good and interesting when driving in a new city, but on the regular drive this could quickly become a subject of a lot of frustration. This feature should be context and location based, for example driving to/from work you only get the about the route and what is happening ahead of the car and when driving in a new city the system can give more information and hints.

Due to double reflection in the windshield in our simulator most of the screen space is needed, because the gauges and text needs to be bigger than the text in HUD that is on the market today otherwise the HUD is useless. This double reflection can be solved with a film that glued on to the windshield. We tried this approach and it worked but it was hard to get in place so we just made a small test to see if this hypothesis was true, but with the film installed the visibility was deteriorating.

Our fourth suggestion for HUD interface design can be though to implement at an international level because symbols does not mean the same as here in other parts of the world, but on the other hand the problem is similar when using text some word that might be three letters here might as well be 14 letters in for example India.

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