CHALMERS

# New Possibilities for Driver HMI

## A study through design on infrared interaction technology

*Master of Science Thesis*

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# Abstract

The Stockholm based company Neonode licenses infrared interaction technology and is moving into the automotive segment. The company now wants to further develop their technology to better suit the needs of the automotive industry and is also in need of case studies that demonstrate the benefits of using their technology to improve the interaction between driver and driver HMI.

The aims of the project were to summarize knowledge about in-car interaction and to give an example of how this knowledge can be realized by creating a demonstrator featuring the Neonode technology.

Recent publications regarding human car interaction were summarized and presented along with a number of crude conceptual solutions, demonstrating some possibilities for automotive applications. In collaboration with the Neonode team, a final suggestion on a new automotive demonstrator was then developed.

The final concept features suggested solutions to several of the problems uncovered in the background study. The final concept aims to keep the driver's eyes on the road and both hands on the wheel. Different ways to provide effective feedback when using touch solutions and a safer way of textual input in the driver environment are also suggested.

The conceptual solution was empirically evaluated against a benchmark solution, the result gave a clear indication that refined versions of some of the suggested solutions, if implemented in cars in a near future, could lead to a safer and more user-friendly driving environment.

# Acknowledgements

Firstly, I would like to give thanks to my family for always being supportive through my years of studying. I would also like to thank my examiner MariAnne Karlsson and my supervisor Lars-Ola Bligård for their commitments to this project.

A special dedication to all the people at Neonode who have been so kind to take time to listen to my presentations and have shared with me their own thoughts and given me feedback regarding my work, especially Ulf Mårtensson who has been my main contact person during the project.

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Finally I would like to mention all the wonderful people at the Industrial Design and Engineering programme at Chalmers. You have made these five last years go by so quickly. I wish you all the best!

# 1. Introduction

## 1.1 Neonode

Neonode was started in Sweden in 2001 by Thomas Eriksson and Magnus Goetz. Initially the company developed and sold its own touch display-based mobile phones, the Neonode N1, N1m and N2 (see Figure 1). These phones featured an interaction system based on infrared light rather than capacitive touch technology. The phones were developed, sold and marketed from the Neonode offices in Sweden and manufactured in Malaysia.

In 2009, based on the previous experience from the mobile business, Neonode changed its business model and has since then been licensing technology rather than developing consumer products. The main Neonode technology is called zForce (zero force) and is today used by multiple companies around the world in applications such as e-readers, phones, tablets, automotive and printers as well as games and toys.

**Figure 1: Neonode N1 (to the left) and the successor Neonode N2 (on the right)**

## 1.2 MultiSensing Technology

Neonode’s patented zForce technology consists of a set of infrared emittors and detectors, a light guide, control electronics and control software.  The emittors project infrared light directly above the touch surface and touch is indicated by changes in lighting conditions. Gestures can be detected by combining measured values form one or several photo detectors.

Neonode has a product segment called MultiSensing technology, which is able to detect touch on any material. The MultiSensing technology may also be used for gesture control using proximity solutions and can detect 3D gestures like the rotation of a finger or a stylus using a solution nicknamed “Stargate”. (Mårtensson, 2013)

## 1.3 Car Integration

One of the latest markets that Neonode is expanding into and see a large potential in is the automotive segment. In-car HMI is a market that is very large and currently undergoing major changes.

During the last couple of years, cars have become more than a mean for individual transportation and people spend a considerable amount of time in their cars while for example commuting to work.

There has at the same time been a significant increase in the amount of functionality offered in the driving environment. Vehicles have become an access point for information, media consumption and personal entertainment. As many of these systems are digital, the car has become a space not only for driving, but also for interacting with miscellaneous systems. Therefore, human factors and usability play an increasingly important role in the interaction design of the different interfaces in the car. One of the main reasons for this is safety. On one hand, the technological advances have made driving safer through driver assistance systems; on the other hand the driver is now more exposed to performing non driving related tasks while the need to manoeuvre the car safely still remains. (Schmidt 2010)

In the early fall of 2012, Neonode began developing interaction solutions specifically designed for the automotive industry. A project was initiated to develop a concept steering wheel that was to demonstrate some of the possible Neonode solutions for automotive applications at the CES expo in Las Vegas in early 2013. Neonode now wants to increase its knowledge in the area of driver-vehicle interaction as well as develop and refine some concepts that can be used to market the technology to companies in the automotive industry.

## 1.4 Purpose, Goals and Delimitations

The purpose of the project has been to increase the knowledge at Neonode regarding Human Machine Interaction in cars, mainly aimed at driver-vehicle interaction with regulators in the driver environment. This knowledge could be used as a basis for future design decisions in the new automotive segment.

The goal has been to provide suggestions of possible implementations of theory through suggesting design guidelines and exemplifying these in a conceptual demonstrator featuring Neonode technology. The design has been benchmarked and compared to existing solutions for evaluation purposes.

The following delimitations were decided upon at the beginning of the project.

- The project will focus on the driver-vehicle interaction with physical regulators in the driver environment. This means that interaction with graphical user interfaces, interaction with regulators outside the car and interaction in the engine compartment, backseat and trunk of the car will be considered only when they are deemed to have an impact on the design of the physical regulators. Halfway to the project, it was decided to focus on integration of controls in a multifunctional steering wheel.
- The functionality of a large number of concepts solutions will be described. Out of these, a limited number of concepts will be selected for further refinement and visualization.
- The level of detail of the final concept solutions will be specified to the extent that manufacturing of a working prototype and comparisons against “on the market-solutions” are possible.

## 1.5 Sustainability

The solutions that were developed in this project related to social sustainability by increased safety through developing safer solutions for in-vehicle interaction. Safety in driving is an area that is important for social sustainability. People should feel safe while moving around in urban and rural environments. Traffic safety, of which the driver environment is a part, is very important from this perspective.

The final solution will have the potential to increase economic and ecological sustainability by reducing the Bill of Materials (BOM) compared to many other solutions that aim to solve the same problem, resulting in less material use and lower costs.

The development of cars is a complex and resource demanding process. In recent years, automotive manufacturers have been struggling with high development and manufacturing costs in combination with dropping sales volumes. If the complexity of the controls in the driver environment can be reduced, this may also contribute to a quicker and less expensive product development process for car interiors.

# 2. Methods and Implementation

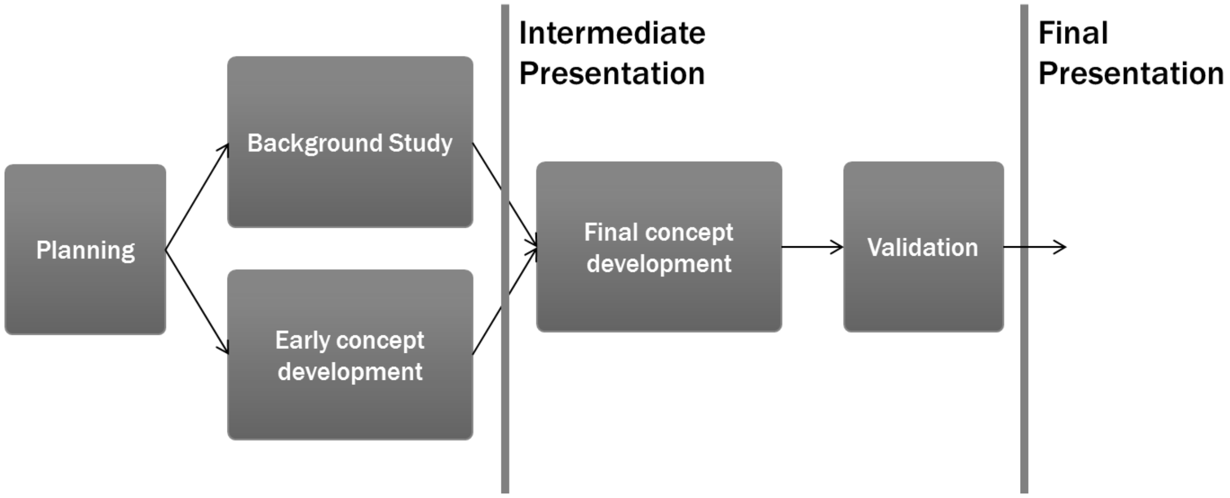
## 2.1 Planning

In the beginning of the project, a planning report was created to define the scope and background of the project and a GANTT-chart (Appendix A) was used for the initial time-planning and to divide the time between the Neonode offices in Stockholm and Chalmers University of Technology in Gothenburg. It was seen as crucial to spend time on site in Stockholm early in the project in order to quickly gain a good understanding of the technology while doing most of the theoretical work at Chalmers with good access to literature.

The project, that started in late October and was scheduled to run for 20 weeks ending in March, was divided into two phases. The character of the first phase was mainly exploratory; summarizing research and coming up with a large number of conceptual solutions that were presented to Neonode. In the second synthesis phase, the learning outcomes from the first phase were summarized in a design concept and evaluated using empirical methods.

The project plan was designed with two parallel tracks in the beginning (Figure 2). to be able to use the inspiration from the background research in creating concepts with the aim to provide a solution to the uncovered problems The second phase was aimed to finalize the concepts to the extent that testing was possible.

Figure 2: Visualisation of workflow during the project



## 2.2 Background

### 2.2.1 Literature Study

Literature studies are used to collect background information for a project and to describe the current state of knowledge within a subject. This is done by searching through different sources for information that could be vital for the project. The sources for a literature study can be of many different kinds; such as earlier documentation, course literature, scientific publications and reports. (Bligård 2010, author's translation)

The focus for the literature study in 3.1 "Theory on Driving" was to find recent research publications and proceedings from automotive conferences. Also considered were textbooks that summarize knowledge in the area of interaction design and human factors for the automotive industry. The findings from the literature were summarized with the aim to find goals for the project and extract guidelines to be used later in the project for good design of regulators in the driver environment.

Literature studies were used to increase the knowledge about other competing technologies in Neonode's main product segment of touch interaction. The findings are presented in chapter 3.3 "Competing Technologies". This was considered as crucial to be able to pinpoint possible advantages of Neonode's technology that could be emphasized in the design or weaknesses that should be minimized.

### 2.2.2 Interview Study

One of the most basic methods for collecting user information is interviews. Interviews can create an understanding of how users think and why they do the things they do. Interviews can be carried out with different degrees of structure. In unstructured interviews a topic is freely discussed with an interviewee, this is preferably done when qualitative data is required. (Bligård 2010, author's translation)

Unstructured interviews were in this project not primarily used to interview users (i.e. drivers), but rather to gain a better understanding of how the theory behind driving is applied in practice through a visit at the Semcon design department in Gothenburg where an unstructured interview with Mr. David Gillblom and Mr. Anders Sundin was conducted. (see result in "3.5 Driver HMI In The Industry") Unstructured interviews was also used to gain a better understanding of the Neonode infrared interaction technology. This was done by interviewing employees at the Neonode offices in Stockholm (see result in "3.2 Technical description").

## 2.3 Early Concept Development

### 2.3.1 Function Listing

A function listing lists and describes the different functions of systems. The functions are then organized into different subgroups, usually primary tasks, secondary task and supporting tasks related to the goals of the human machine interaction system. The function listing can later be complemented with technical principles. (Bligård 2010, author's translation)

A simple function listing was completed out to define the design space for the project. The function list was used to generate design concepts that could execute the described functions. The function listing was used as a basis for discussion on which conceptual solutions and which functionality that were suitable to be included in the final concept.

A more elaborate function listing (see chapter 5.1 GUI) was conducted to break up the functions into sub-functions that were to be included in the representation for the usability test into sub-functions. This also provided the basis for the GUI development.

### 2.3.2 Gesture Sketching

The gesture sketching method was created specifically for this project because there was a lack of methods to aid the idea generation and design of interactions as well as a lack of methods when the desired solution is of a non-visual nature. Sketching a driving environment and then trying to describe the movement of hands and other body parts on paper was found to be much too time-consuming and did not communicate in a good way how well the interaction might work. Therefore the method of gesture sketching was created.

Gesture sketching requires a representation of the interface that the interaction will take place in and a device that records video. Video is then recorded while the designer(s) uses the representation of the interface to try out different physical interactions. This documents the different ideas in a highly realistic manner. The video can later be edited with textual descriptions or symbols further clarifying the intent of the interaction. The video can be used as a basis of discussion during the design process as it gives viewers an indication of how the interaction would feel and work in an actual situation.

Gesture sketching was used in the project as an idea generation tool. A Volvo C30 from 2008 served as a representation for the method. Self-adhesive stickers were used to mark out possible areas where sensors could be added to the car. The designer (the author) then sat in the car and was recorded while trying out different interactions during the course of a day. The video recording was then edited to simulate the systems response in order to give an understanding of which effects the interactions would have. The video was later used as presentation material at the intermediate presentation and as a basis of discussion on the future development of the final concept.

### 2.3.3 Future Development and Filtering

After the intermediate presentation, the scope of the remaining part of the project was discussed and a decision was made to come up with a concept that included the most interesting functionality and that was feasible to achieve with the time remaining.

The discussion at the time of the intermediate presentation was used to evaluate which concepts were to be included in the final solution. A large number of concepts were reviewed, but it was clear that some had larger potential and others required little effort to include in the final scope.

## 2.4 Final Concept Development

### 2.4.1 Sketching

Sketches can be used to visualize and communicate designs. There are different types of sketches such as hand sketches, digital sketches and marker-renderings.

Sketch models are a type of 3-dimensional sketches that can not only communicate the design and visual appearance of an object, but also evaluates size and physical ergonomics. (Österlin, 2003, author's translation)

To integrate the suggested functionality in a design concept, sketches were made that featured all the suggested functionality. Initially the goal was to explore different possible shapes of a conceptual steering wheel without many restrictions, why a large number of hand sketches were generated; exploring different design possibilities.

The most promising design tracks were selected for further visualization using digital sketches, and the most promising sketch was turned into a sketch model using KAPA-board and tape. The sketch model was then used to evaluate measurements for satisfactory physical handling and photos of the model were used as underlay for the CAD. Additionally, the model was used as a representation in the Formative Evaluation (see 2.4.2 Usability Testing).

The Graphical User Interface (GUI) for the representation was developed through iterative sketching using various sketching tools such as Photoshop and Fireworks. PowerPoint was used for the final layout and to add dynamics to the GUI.

### 2.4.2 Usability testing

A usability test lets a selection of test subject conduct a series of tasks with a representation of the product that is to be tested. The method is used to evaluate the level of usability of a product and its interface but can also successfully be used to compare different product designs among each other to get a benchmark. (Jordan, 1998) The result of the usability test is largely dependent on the environment in which the test is conducted. The more realistic the test set up is and the closer to the use-situation the test situation is, the more valid the result.

The parameters measured during a usability test can be quantitative; such as number of errors, time to execute a task or number of clues required for the test subject to solve the task at hand. Just as important as quantitative measurements are qualitative measurements. Qualitative measurements can for example be specific problems encountered or comments from the test subjects regarding the interface.

During a usability test, the test subject is presented with the task by means of either written or oral instruction. Usually a moderator is in charge of the testing and presents the tasks to the test subject. The moderators' influence on the test result is large, why it is important that the moderator treats all test subjects equally and that there is always a note made if the test subject requires extra explanation beyond the instruction of the task.

Figure 3: Set up for the formative evaluation

The selection of test subjects is also important for the outcome of the usability test. Test subjects are for instance likely to perform better if they have a high level of domain knowledge, i.e. are familiar with similar types of systems than subjects that have little experience in dealing with such.

**Formative evaluation**

A type of usability test, the formative evaluation is part of an iterative process that aims to identify and resolve usability problems with a concept during the concept development stage of the product creation process (Jordan, 1998). A representation of the product is used, and much like in a regular usability test, a group of test subjects is asked to perform tasks with the mock-up product in order to evaluate the design. The main way in which a formative evaluation is different from a standard usability test is that the representation of the product is modified in between test-runs whenever a problem is uncovered. This is done in order to gradually improve the performance of the product interface while getting continuous feedback on the effect of the changes.

In this project, formative evaluations were used in the concept development phase in order to discover and resolve usability problems before evaluating the final concept.

A table-top representation of the system was used for the formative evaluation (see Figure 3). It consisted of the sketch-model that had already been made for the physical evaluation mounted on a rotating stand. The stand was made from wood and the wheel of a trolley. As a Head-Down-Display (HDD), a 13.3 inch LCD-screen controlled by a laptop was used to power a PowerPoint presentation displaying the HDD-GUI. The Head-Up-Display (HUD) GUI was shown using a USB-compatible pico-projector that could be controlled using a remote. The GUIs are presented in their final version in chapter 5.1.

The formative evaluation was done using 10 test subjects aged between

21 and 64. The subjects performed six consecutive tasks in one run, with a total of two runs in order to measure the learnability aspects of the system.

The tasks were the following:

1. Navigation:
   Add new destination
2. Wipers:
   Activate wipers at highest speed
   Shut of wipers
3. Lights:
   Activate high beams
   Deactivate high beams
4. Audio:
   Play song from playlist
   Decrease volume
5. Climate:
   Set temperature to 22
6. Telephone:
   Call Contact.

The execution of the tests were similar to the benchmark test described in chapter 6.2, but since the prototype was changed in between test runs, and the results only tracked individually summaries of this test data is not presented.

## 2.5 Validation

### 2.5.1 Kano Analysis

The Kano Analysis is based on the Kano Model of customer satisfaction, named after its inventor, Japanese professor Dr. Noriaki Kano. It is a tool used to evaluate the quality/customer satisfaction that a function would add to a product. The method uses a questionnaire to ask potential users about their estimated satisfaction level of different functions. The data is then analysed to define the functions in three different categories; threshold, performance and exciters. Threshold functions must be implemented to achieve an acceptable level of satisfaction, implementation of performance functions have a linear effect on the satisfaction, while implementation of exciter functions only have a positive effect on the customer satisfaction.(Brusse-Gendre, 2002)

As a validation of the attractiveness of the concepts featured solutions and functionality, the functions were evaluated using a Kano analysis questionnaire that was handed out to 15 persons aged between 21 and 64.

The result of the questionnaire was compiled and the functions were characterized according to which functional category they belonged to. This was done by dividing the number of user that saw this function as belonging to that category with the total number of users. This value was then used to illustrate the functions position in the Kano Model chart. A value close to 1 (eg. all the users agree on the belonging of this function) put the graph tangent to the line used in the KANO model to illustrate this. A value of less than 1 makes the line deviate away from this position.

If the respondents were uncertain to how the function affected their satisfaction. These users were omitted from the calculations, and an uncertainty-factor was added dependant on the number of users that stated their uncertainty or functions lack of effect on their satisfaction level.

In this case, it was not crucial to get an exact mathematical value of the characteristic; hence, the calculations were therefore simplified and plotted by estimate.

### 2.5.2 Benchmark test

A usability benchmark test was carried out in order to evaluate the performance of the prototype compared to a solution on the market today.from a usability perspective. The methodology of a usability test has already been described in chapter 2.4.2. The execution of the tests will be described in coherence with the results in chapter 6.2. This order has been decided because the test method was based on the results of the concept development. Hence, the validation of the concept will be easier to follow once the concept has been presented.

# 3. Background

## 3.1 Theory on Driving

### 3.1.1 Rationale

Designing interaction for the driver environment is demanding because it places high demands on the quality of the design of both input (e.g. controls) and output (e.g. displays) devices. The reason for these high demands is that driving itself is a complex cognitive process that requires the driver's full attention. The process should therefore not be disturbed by adding cognitive loads on the driver through interaction with other devices than those used for driving. There is however an increasing demand for functionality in the driving environment, which is why it is even more important for safety reasons that the increased functionality is well designed from a human factors perspective.

The automotive industry places high demands on all controls and displays that are implemented in cars. There is a legitimate concern among safety experts and organizations that new technologies for interacting in a car may overload the drivers' information processing and distract him/her from the primary driving task (Bhise 2012). Based on this, most major car manufacturers have employed human factors professionals dedicated to developing, improving and testing new solutions (Gillblom 2012). It is consequently important for suppliers of software and hardware to be in agreement with the requirements placed upon their products from these perspectives.

### 3.1.2 Driver Information Processing

Driving is one of the most complex processes that people learn during the course of their lifetime. The combination of actions triggered by different inputs and the coordinated motor skills required for driving is something that takes a considerable amount of time to learn for most. Beginner drivers often find changing gears more or less impossible. Novice drivers are often so preoccupied by the spastic positioning of the vehicle that they do not properly scan the environment for potential dangers, but rather look at the road straight ahead of them, something that may cause accidents. (Underwood et al. 2007)

The car can be viewed as a complex human machine interaction system where the actions of the human performed on the controls give input signals to the functionality of the vehicle that are being displayed using visual, kinaesthetic and auditory output. In accordance with Normans model of human information processing (Figure 4) the driver's ability to give the vehicle the correct input is limited by the following factors: The driver's attention to the system feedback, the driver ability to operate the system, the driver's knowledge about the system, and whether the driver's mental model of the system corresponds well to the actual design. (Bohgard et al. 2008)

Once a driver has overcome the initial learning phase and has adjusted to his/her specific vehicle, there is some cognitive capacity to spare for the driver to handle other tasks while manoeuvring the vehicle in a relatively

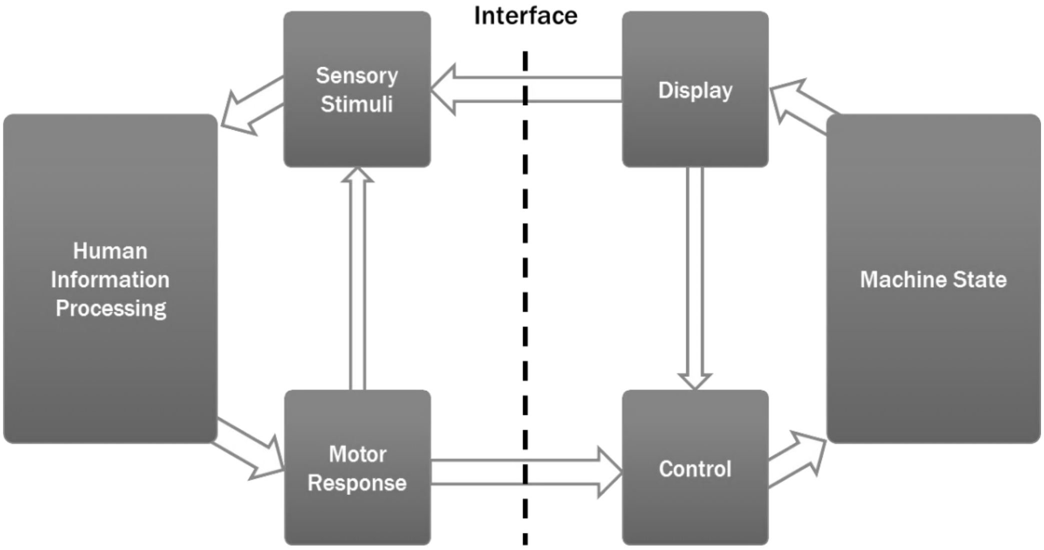


**Figure 4: Model of human information processing based on Norman (Norman 1986)**

safe manner. This can include having a conversation or operating audio equipment, navigation systems or climate control.

In order to drive safely, drivers need to stay in their designated lane, maintain an appropriate speed and spacing to other cars, navigate bends and corners by turning the steering wheel and be able to avoid hazards by braking. In order to do this, the driver should direct his/her gaze mainly in the direction of movement, which is most often straight ahead, but the driver also needs to divert his/her attention in other directions for certain periods. These diversions last from 0.5 to 1 second for rear view mirrors to several seconds and multiple glances for other in-car equipment such as radios and climate controls. These visual and motor interaction tasks may compete with the demands of driving. (Underwood et. al 2007)

### 3.1.3 Multimodality in Driving

The most important sensory organ for a driver is vision. For the driver to safely interact with the surrounding environment, he or she needs to have a clear view of it. The many aids installed in cars, such as mirrors, parking assistance and driver assistance systems are testament to this need.

In 1996, Sivak mapped 89 of the most important of the behaviours to the sensory input that was required to execute the behaviour. The result of the mapping was that vision is by far the most important sense with 83% of all behaviours dependant on it, 11% of all behaviours are dependent on kinaesthetic input, 6% are dependent on tactile input and 1% is dependent on auditory input (see Figure 5). 33% of the behaviours are dependent on more than one sensory modality (Sivak 1996). It has however frequently been argued that more than 90% of the input for driving is visual. This could also be supported by Sivak's findings if for example the visual input vs. the kinaesthetic input was weighed during the course of an action, according to

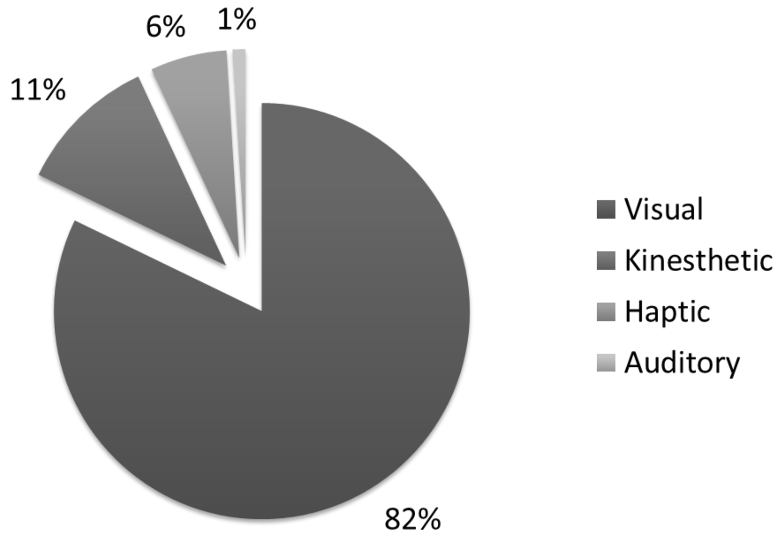


**Figure 5: Histogram of information modalities**

importance rather than divided evenly between the two sensory inputs as done in Sivak's analysis.

Non-visual output cues do not require the driver's visual attention to the same extent that visual cues naturally would. Hence, non-visual cues have less risk of overloading the driver's visual attention. It has furthermore been suggested that non visual cues have a more rapid information processing, a more automatic ability to cause a reaction and that they cannot be switched of voluntarily (by for example shutting eyes). (Ho et al. 2008)

To further ease the visual load on the driver, it is recommended that haptic feedback is used for most controls in the driver environment. Touchscreens often lack built-in haptic feedback but there are technologies that can add this haptic feedback to most touch devices. In a recent publication, Arasa Gaspar recommends using surface texture changing technology for the purpose. This technology improves the usability of controls used to navigate between different items and for selecting levels.  (Arasa Gaspar 2012)

### 3.1.4 Reaction Time

The driver's interaction with the driver interface can be modelled using an information processing model such as the one in Figure 6. For a driver to be able to react to a stimulus, the stimulus first has to be detected by the receptors (eyes ears, fingers etc.). The response is then dependant on the drivers' perception of the situation, which in turn is dependent on his/her previous experiences of similar situations. All of these steps are processed by a limited supply of cognitive attention resources. (Wickens et al. 2004)

The time it takes to carry out a task is dependent on the time it takes to carry out the individual steps in the model which are in turn dependant on the cognitive resources it takes to process these steps. The more complex a task, the more time it takes to execute it. Things that can increase the complexity of a task are for

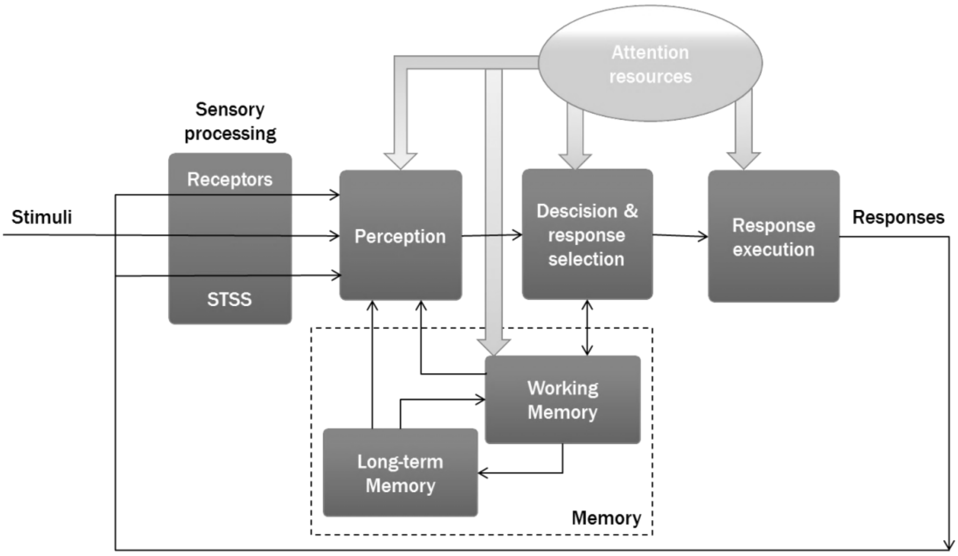


**Figure 6: Wickens' model of the information process**

example the number of items to choose from in a menu, the number of sequential actions or steps, and the number of motions required to operate a control. The model also states that the user's memories and previous experience of the system are important.

As previously stated, tasks that are quite simple in their composition take only about 0.5 to 1 second to execute (e.g. checking rear-view mirrors or speedometer), but more complex tasks require longer time. When for example selecting a radio station or changing the temperature in the car, this is typically done in two to four glances, each glance lasting for about a second. When a car travels at 100 km/h, it travels 28 meters in one second. It has been shown that 2.5 second glances lead to difficulty in keeping the car in the designated lane, why it is suggested that equipment in the car is designed so as to be operated with as few glances as possible and with no glance lasting longer than 1.5 seconds. This is further supported by the fact that drivers driving at high speeds (100 km/h) are not willing to close their eyes while driving for more than 2 seconds during easy driving conditions and not for more than 1 second during difficult driving conditions. (Bhise 2012).

Reaction time can be calculated using laws such as Hick's law. According to Bhise (2012), the following factors affect the reaction time, even if the list does not claim to be complete:

*"a. Type of sensor or sense modality (e.g. mechanical sensors in human ear have shorter delay times than photochemical sensors in the human eye)*
*b. Stimulus discriminability or conspiciuosty with respect to the background or other stimuli (signal-to-noise ratio or clutter)*
*c. Number of features, complexity, and size of feature elements in the stimuli*

*d. Amount of search the human operator conducts (e.g. size of search set)*
*e. Amount of information processed (uncertainty and number of choices and their occurrence probability)*
*f. Amount of memory search*
*g. Stimulus–response compatibility (e.g., how similar is the mapping or association of the stimuli to the responses)*
*h. Alertness of the subject*
*i. Motivation of the subject*
*j. Expectancy (how expected, or known from past experience is the event, in terms of when and where it could occur)*
*k. Mental workload (other tasks that the subject is time sharing at that time)*
*l. Psychological stress (e.g. emotional state of the subject)*
*m. Physiological stress (e.g. tired, fatigued, or in an environment affecting bodily functions)*
*n. Practice (how familiar or skilled is the subject to the situation)*
*o. Subject's age (older subjects are usually slower and more variable)"*

(Bhise 2012, chapter 6, p. 60-61)

When a reaction has been determined, there is an additional time taken to make the physical movement required by the decided action. According to Fitt's law of movement (Fitts 1954, Fitts et. al 1967) this time can be reduced by (i) reducing the movement distance and (ii) by increasing the size (width) of the target control, thus reducing the need for accuracy.

### 3.1.5 Layouts

A large body of laboratory research has shown that driving performance deteriorates when drivers have to divide their attention spatially. This means to focus all their auditory or visual attention in multiple directions as opposed to one. It has been shown that handling multiple tasks at the same time while driving leads to a more dangerous driving behaviour (Ho et. al. 2008). The implication of this is that driver attention should not be averted from the main task of driving, that is mainly visual and directed towards the environment surrounding the vehicle.

The driver environment for personal vehicles is heavily standardized, and as a result, the layout of the main functionality of the car is very similar between models and brands. Tönnis (2006) divides the tasks of driving into three different categories: Primary, Secondary and Tertiary tasks. These tasks are then plotted into a driver environment according to the spatial location of the function that supports the desired task (Figure 7)

Primary tasks are directly related to manoeuvring the vehicle in the surrounding environment. These tasks are today controlled mainly by devices such as the steering wheel and the pedals (and in case of the manual transmission, the gear stick). The suggestion is that information regarding these tasks is positioned in a place that is easy for the driver to perceive, since the information is Important for the driving process.

Secondary tasks are tasks closely related to the driving capacity and safety of the driver such as using windscreen wipers and turning indicators. The interfaces for controlling these tasks should be mapped in an easy to access area close to the focal perspective of the driver and within easy reach.

Tertiary tasks are not directly related to driving, but are rather there in order to enhance the driving experience. The location of devices for executing these tasks are not of the same importance as the previous two categories, but should still be placed within the reach of the driver and perhaps as well within reach of the front passenger. The center stack is often used for this.

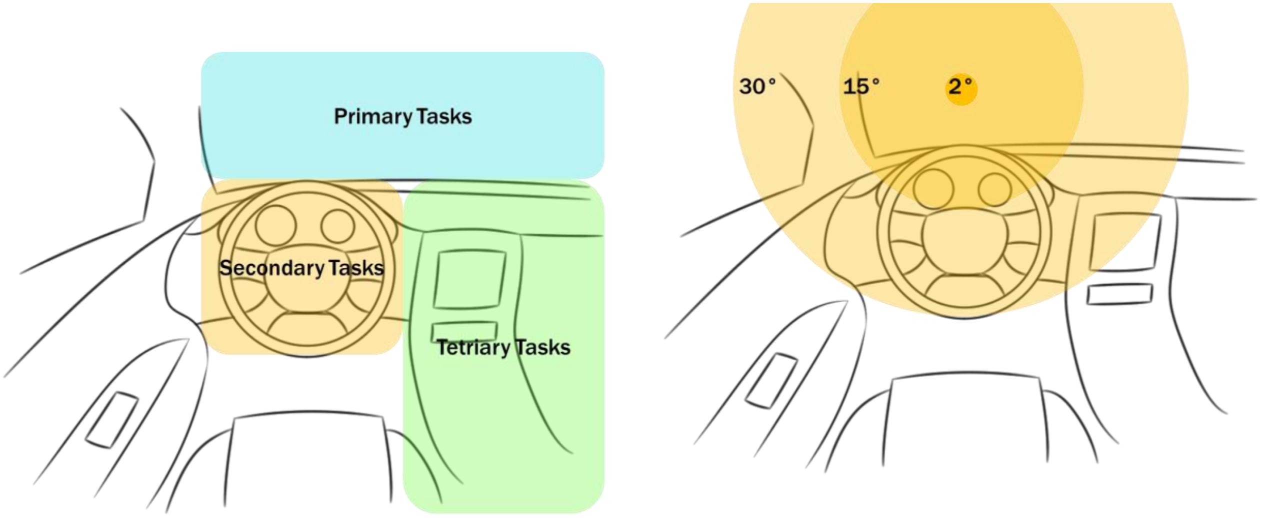
The task layout is based on the human visual capacity. The eyes ability to notice changes in the environment decreases the further away from the visual centre of attention the change occurs. It has been suggested that displays placed beyond 15 degrees away from the central field of vision are not clearly seen and that there is another border around 30 degrees where peripheral information can be accurately detected (Figure 8).

### 3.1.6 Design of Devices

The need for better devices in the driver environment was first uncovered when Fitts and Jones analysed errors committed by pilots during the Second World War and concluded that many of the errors could have been prevented by equipment that was better designed to fit human needs. (Fitts et al. 1961)

The area of devices is often divided into input and output modules as in the Human Machine interaction system (See Figure 4: Model of human information processing based on Norman).These modules are however often overlapping, as is the case for touchscreens that are becoming increasingly prominent in driver environments (Kern et al. 2009), which is relevant for this project. The basic design principles of input and output devices are also largely overlapping. They should both be used with a minimum amount of short eye-glances, no large movements should be

**Figure 7: Task layout based on Tönnis (2006) and field of vision based on Tretten (2008)**



necessary and physical as well as cognitive loads should be minimized during the use of both types of devices. (Bhise 2012).

### 3.1.7 Different Types of Devices

There are many different types of devices that the driver can interact with in a car. Here follows a selection of those that often are used in cars and/or are relevant for this project. The items in this list may be used instead of the word device in the following section *3.1.8 Design Guidelines for Devices*.

1. Displays: There are many different types of displays; basically anything that transmits information to a user is a display. It can be a symbol, a light on a button, a gauge or a large screen displaying a huge variety of different information. It could be possible to classify the screen as a compound of different displays and refer to the individual elements as display units.
2. Buttons: Buttons refer to regular buttons that are activated by a pushing motion. They can be present in virtual or physical form and sometime incorporate a visual, tactile or auditory display to indicate status. Buttons are often discrete, meaning that they only have a set amount of modes, often on and off.
3. Stick switches: Stick switches are protruding levers that have two or more settings. They can have either discrete or continuous input as in the case of joysticks, but are often simpler as the controls used to open and close windows. They give a visual and haptic feedback to the mode that they are set to, but this can require strengthening in order not to be a source of errors.
4. Rotary switches: Rotary switches are often used to increase or decrease flow, but can also be used when selecting alternatives in a menu. Generally clockwise means increased flow or forward and counter clockwise means decreased flow or backwards.
5. Multifunction switches: Multifunction switches are often used in today’s cars in order to reduce the number of input devices. One-to-one mapping is not always possible as for example a BMW in 2009 contained more than 700 functions (Kern et al. 2009). The multifunction switches are often a combination of the previous switches like in the case of the steering wheel stalk. It can be flipped to different settings like a stick switch, rotated as a rotary switch and usually has buttons that can be pressed.
6. Touchscreens: Screens and touchscreens are increasingly used in today's vehicles. They can reduce the need for motor-movement needed to manipulate controls and can contain a multitude of different displays and controls. Most touch displays require, however, visual attention due to their lack of haptic feedback. They may in addition not be suitable for use with e.g. gloves or long finger-nails and may also be more susceptible to dirt, wear and reflections. (Bhise 2012).
7. Gesture recognition: A more recent interaction device that (to the author’s knowledge) has not yet

entered production in cars is gesture interaction. It uses optical, audial or electric sensors to track 3-dimensional gestures performed by for example a hand or any stylus. Gesture recognition has the possibility to reduce the visual demand of the driver through controlling an interface using a less exact spatial orientation than is allowed by most traditional interfaces. (Döring et al. 2011)

### 3.1.8 Design Guidelines for Devices

There are some general guidelines for devices used in a Human Machine Interface that can be applied also to the displays and controls in the driver environment. Driving has some specific requirements that are discussed in previous sections. These guidelines all strive to minimize the cognitive and physical load of the driver.

A selection of suggested guidelines are presented below.

1. All devices should be operable with as few glances as possible and should contribute as little as possible to visual overload of the driver. If possible the devices should be operable without the need of visual information. (Bhise 2012).
2. The system should provide easy to understand feedback on what happens when an input is received. At all times it should be easy to inspect the status of the HMI system as well as find the way out of the action flow. (Bohgard et al. 2008)
3. The devices that are most important for the use of the vehicle and those that are used most often should be placed close and within easy reach of the driver.(Bohgard et al. 2008)
4. Driver information that is urgent for the circumstance should be placed as close to the traffic scene as possible. (Tretten 2008)
5. All interaction should try to emulate reality so that the user more easily can understand the system. For example, if a manipulation of an input device occurs in a downward direction, this should also be replicated in the system by a similar downward reaction. (Bohgard et al. 2008)
6. The order of information and actions should be structured spatially in a logical way according to the order that they are used. This sequence should be reoccurring throughout the whole system. (Bohgard et al. 2008)
7. The devices in a system should function in a similar way that they do in other systems that the user might have experience from. (Bhise 2012). This is sometimes referred to as external consistency. There are many different standards for this such as ISO or SAE standards that include for example different symbols for an array of different functions in vehicles.
8. Controls and displays should be grouped after functionality (Bohgard et al. 2008).
9. Similarity between objects that do not have the same function should be avoided (Bohgard et al. 2008).
10. One should use multimodality in senses and multiple sources of information to make the user react more quickly to important events (Bohgard et al. 2008). This is especially important in warning

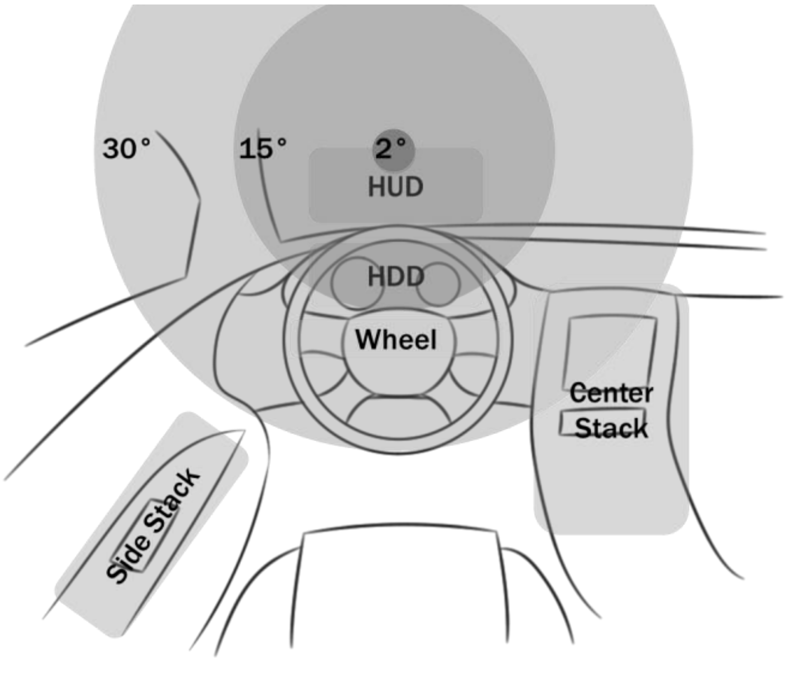
systems, where is has been shown that users react more quickly using a combination of different sensory modalities. (Ho et al 2008).

11. All controls should require a minimum amount of movement to operate (Bhise 2012).
12. The physical properties of the controls should be such that they do not require any strain and a minimum amount of precision to operate. They should feel comfortable to use. (Bhise 2012).

### 3.1.9 Conclusions and Design Implications

The design guidelines used in the driving environment differ from general design guidelines in HMI interaction mainly because of the heavy impact that the visual information processing has on the driving task. This has two major implications. One is that driving is more dependent than many other tasks on multimodal feedback. The other is that the relation between the items 3 and 4 in the design guidelines has a slight discrepancy. It concerns the position of the controls and the displays. One of the guidelines rates the importance and frequency of use of the devices in order to figure out the spatial positioning of displays and controls, while the other bases this importance on which information is needed for the circumstance. Neither of the statements is wrong, but traditional approach, exposes the driver to a high risk when executing a task considered less important by not having these less important controls and displays conveniently located. During these circumstances, the controls should be temporarily moved to a more convenient location, reducing the risk exposure. This is entirely possible with today's technology. This is also supported by NHTSA Guidelines stating that active displays should be placed as close to the line of sight as practical (Strickland 2012). Figure 8 shows the drivers field of vision over the controls.

**Figure 8: Overlay of field of vision on layout of controls**



## 3.2 Technical Description

To gain a better understanding of the Neonode technology before the concept development phase, a technical description was generated through unstructured interviews at the Neonode offices in Stockholm, Sweden. (Mårtensson 2012):

The technology is used in many different devices such as smart phones, tablets, e-Readers, toys, printers and for automotive touchscreens.

### 3.2.1 Optics

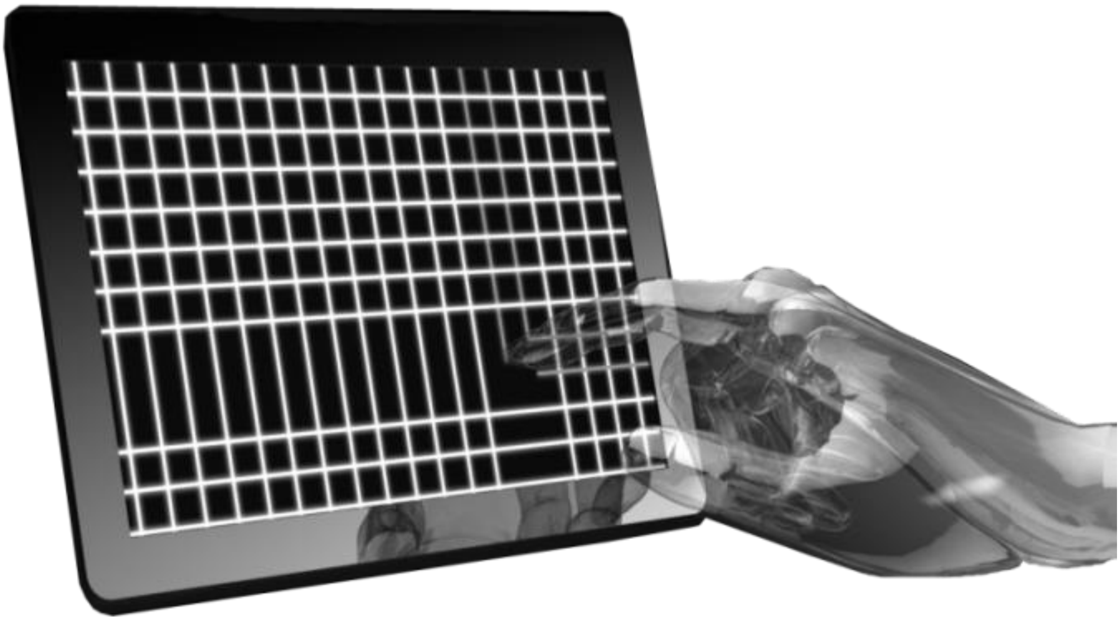
The Neonode patented zForce technology is based on infrared light and originally derived from the Neonode smartphone. Light Emitting Diodes (LEDs) are placed on a circuit board that emits infrared lights through a patent-protected plastic frame called light guide that filters and directs the light. This light is then projected in a grid-like pattern across a surface (Figure 9) and detected by several Photo Detectors (PDs) on the opposite side of that same surface.

When an object such as a finger shades the PDs from the light emitted by the LEDs, the PDs detect this and provide coordinates that can be used to decipher the touch point to an external interface. Today, the technology can handle two touch-points of down to 1 mm in size, but current research will soon increase this number to five or more. High resolutions are possible, which allows the display to track handwriting with even a gloved finger or a stylus.

### 3.2.2 Mechanics

The light guide is wrapped around the screen and projects the light above it. This requires the height of the edge to be at least 0.5 mm (preferably higher for better performance) in order to project the grid properly. Therefore, the light guide cannot be in level with screen, but has to be slightly above

Figure 9: Explanation of the infrared grid (image couertsy of Neonode)



the screen, creating a frame (much like in a painting). The light guide can guide the light in different directions due to its total inner reflection property, but is due to this phenomenon sensitive in the reflecting areas. (See Figure 10 for cross section of system)

The touch surface, which can be made up from of any material, can be flat or slightly concave, but not convex due to the fact that light cannot bend around it.

The light guides are usually manufactured in polycarbonate (PC) by means of injection moulding. They can also be manufactured in PMMA (commonly known as Plexiglas), Due to the better construction properties of PMMA, it is often used for prototyping.

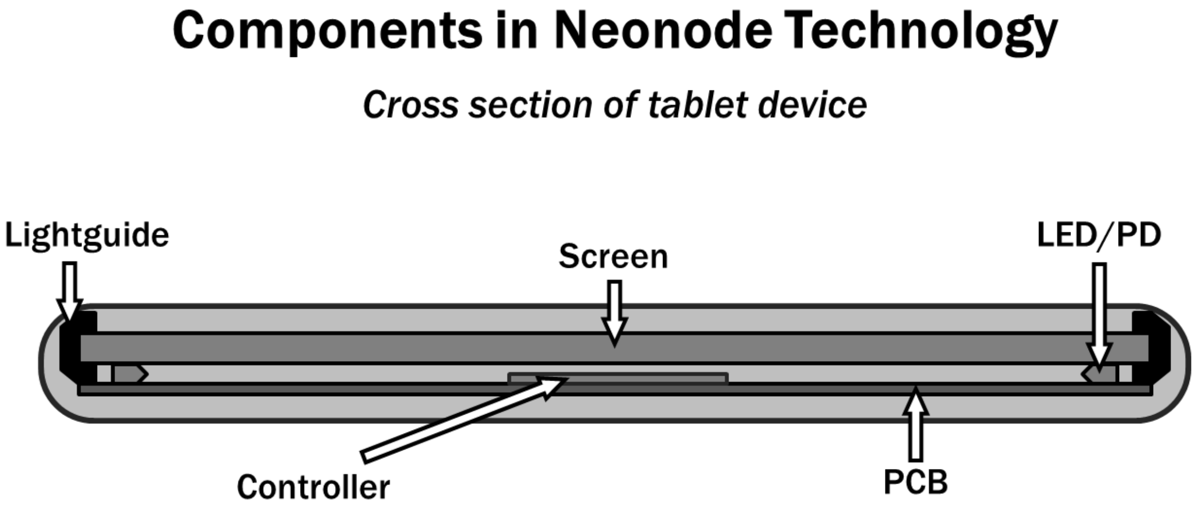
### 3.2.3 Hardware

The control hardware such as LED drivers, amplifiers, multiplexers, voltage regulators and filters are all integrated in a chip that Neonode recently has developed in close cooperation with Texas Instruments. The merge of this functionality into one chip allows for a lower cost of the bill of materials and a smaller printed circuit board footprint. It additionally allows for a shorter time to market as the standardized Serial Peripheral Interface (SPI) making the integration of the technology in different products much simpler. Scanning speeds of up to 1000 Hz are possible, resulting in response times of down to 1 millisecond. The technology also has five to six times lower power consumption compared to some competing technologies. This new hardware makes it possible to save touch point history, something that gives shorter response-times and adds a possibility to track more advanced gestures.

### 3.2.4 Automotive Application Challenges

Some of the technical challenges regarding the automotive applications of Neonode technology are the longer product life that the consumers expect from their vehicles compared to most consumer electronics products in which the technology is usually

**Figure 10: Component description**



featured. Furthermore, the automotive industry requires a much higher durability with regards to external temperatures. This could be an issue due to the thermal expansion of the plastic that the light guide is comprised from. The light guide has been developed to operate in conditions ranging from -40°C to +85°C but this has to be validated further. In addition, the grid is sensitive to water-droplets that may break the light, but has software algorithms that can compensate for dust or other particles on the touch surface as well as variations in component quality.

### 3.2.5 Future Development

The Neonode technology can not only be utilized to recognize touch over a surface. Infrared technology is also widely used for proximity detection. In the case of proximity, the LEDs are aimed outwards from the surface, and any object in the vicinity of the surface will reflect some of this light, which can then be detected by PDs. This is similar to the technology that exists today in many automatic faucets in public restrooms. It is possible to detect not only position, but motion towards and away from the LED and PD pair.

If the light guides are layered, it will not only be possible to detect position in a 3rd dimension but full 3D rotation too. Neonode calls this application "Stargate". The advances in hardware signal processing make it possible to save history for the motions.

Furthermore, the technology has potential to add multi touch and proximity to curved surfaces as well as recognize 3-dimensional gestures. This means that you can create a touch and 3D gesture tracking surface with any shape and many different surface textures as long as the surface is transparent or semi-transparent. The light guides can be tinted in a variety of different colours, but the most commonly used (so far) is black.

## 3.3 Competing Technologies

There are several technologies for achieving touch integration on screens and other surfaces. Many of these compete directly with the infrared-grid based technology that Neonode utilizes. An overview of some of the more common competing technologies follows.

### 3.3.1 Capacitive Touchscreens

A very commonly used technology for achieving touch interaction is capacitive touch technology. This technology is based on a (weak) electric current, so that when a conductor touches the interaction surface, the change in the electrical field can be measured and the point of contact calculated. There are different types of capacitive touch, which are used in different applications depending on the accuracy required. Capacitive technology can support multi-touch and is widely used in applications such as smartphones, track pads, and tablets. Most capacitive touchscreens however depend on the prerequisite that the finger or stylus touching it is a conductor. (Cirque corporation, 2011)

### 3.3.1 Resistive Touchscreens

Resistive touchscreens require two, otherwise insulated, conductors to be squeezed together in one point, forming a current which can be used to deduce the point of touch. Resistive touch technology is insensitive to the electrical conductivity of the stylus, but has in later years been eclipsed by the capacitive technology. (Cirque corporation, 2011)

### 3.3.2 Frustrated Total Inner Reflection

Frustrated total inner reflection uses the property of total inner reflection in acrylic materials by projecting infrared light into them. The acrylic material then becomes the touch-surface that, when touched, calculates the position of the touch point by detecting the disturbance that occurs in the light-field when the total inner reflection is interrupted by another material coming in contact with the acrylic. The change is detected by an infrared camera. The limitations of this technology is that an acrylic needs to be used as the touch surface and that it is sensitive to dirt, grease and liquid that may disrupt the infrared light. The technology however supports multi-touch. (Blindmann, 2011)

### 3.3.3 Optical Imaging

Optical imaging usually uses infrared projected over a rectangular surface. The change in the light is then detected by detectors in the corners of the surface that triangulates the position of the point of touch. Optical imaging can be scaled with little cost to fit larger screens, but is more sensitive to dirt and other particles than the intended stylus that may break the light. In the configuration with four detectors, it supports dual touch. (Blindmann, 2011)

### 3.3.4 Acoustic Pulse Recognition

Acoustic pulse recognition utilizes the fact that the contact with and movement on a glass surface create sound waves in the glass. The sound is detected and the position is calculated in a way that is similar to that of dispersive signal technology. The technology cannot, however, calculate positions for multi-touch. (Blindmann, 2011)

### 3.3.5 Force Based Touch

Force based touch uses sensors on a screen that calculate the point of touch based on the proportion of the force that is divided over the sensors. The technology is very insensitive to dirt and other particles, but at the same time uses mechanical components that may be subject to wear. It can detect pressure, but is only single touch capable. (Blindmann, 2011)

### 3.3.6 Incentives for Neonode Technology

Incentives for using Neonode technology are among others (Mårtensson 2012):

- The low price - The zForce is marketed as an affordable technology. In quantities over one million units, a price of 1 USD per screen-inch is feasible.
- The low energy consumption - zForce outperforms capacitive displays and many other solutions when it comes to energy consumption. At 100 Hz one unit is at 1 mW.
- High speed and precision - Scanning speeds of up to 1000 Hz are possible.
- Short turnaround time and low technical risks - the Neonode solutions are not mechanically complicated and are based on well tested infrared technology.

These incentives suggest that Neonode’s technology is competitive mainly when it comes to price, but also in performance and from the standpoint of ecological sustainablilty.

## 3.4 Trends in Driver HMI

Semcon has a strong connection to the Volvo CC and Volvo AB. The design department does a lot of work and research in the field of Driver HMI. Much of the work has traditionally been focused on minimizing or eliminating the number of glances or ”eyes off road time” that the driver uses to operate instruments in the driver environment.

Recently, the introduction of Head-Up-Displays has meant that it is possible to create HMI designs which allow the driver to operate instruments while keeping his or her eyes on the road. This means that some often used testing methods, such as occlusion goggles, may be obsolete and new testing methods may have to be developed if the HMI system incorporates a Head-Up-Display.

There has also been a lot of interest for tracking driver intention. By monitoring the behaviour of the driver and the surrounding environment, it is often possible to predict the actions of the driver and adapt the instrumentation to better suit the contextual needs of the driver. A technology that is interesting for this is motion tracking technology such as LEAP, or Kinect technology or potentially infrared proximity. Motion tracking technology has the potential to support a gestural interaction system that may reduce the need of visual orientation in the driver environment.

Additionally, different types of haptic feedback in the driver environment have been an area of interest for the automotive industry for many years, and many different solutions have been tested. A field that Semcon is currently doing research in is the use of haptic feedback in touchscreens, which suggests that this area is of interest to car manufacturers. (Gillblom 2012)

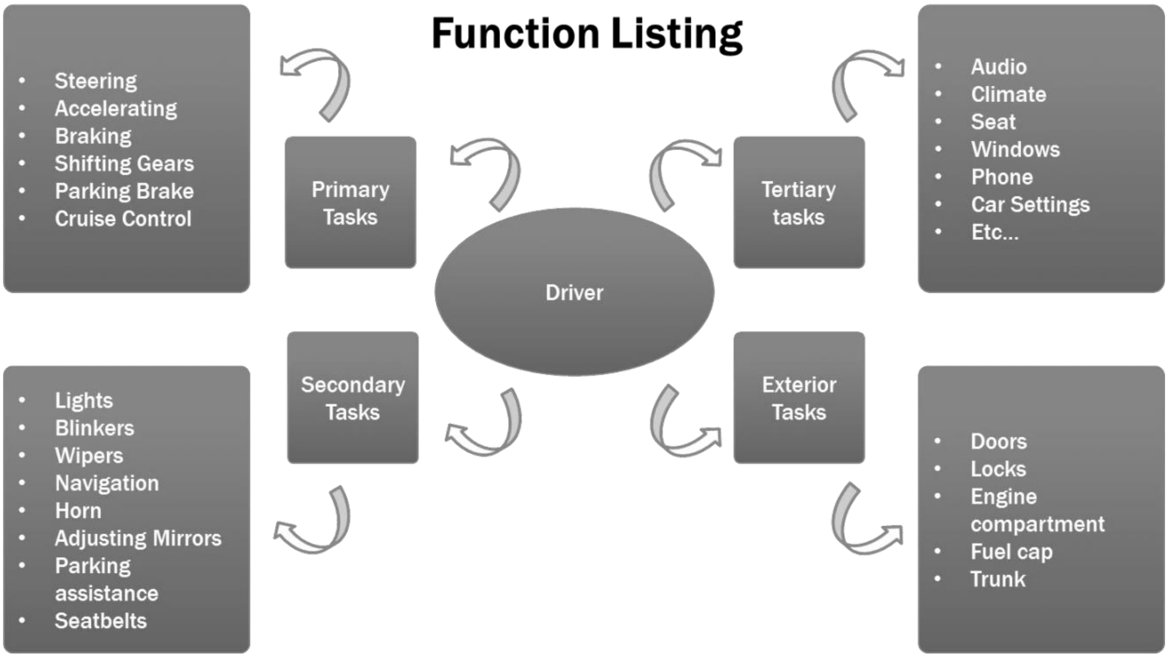


**Figure 11: Initial function list**

## 3.5 Function Listing

The functions that can be accessed in most modern cars can be divided into the groups; primary tasks, secondary tasks, tertiary task and exterior tasks. This division is based on the task layout of Tönnis et al. (2008) previously referred to in the theory section. (See Figure 11)

The primary tasks are directly related to driving, and any removal of such a task would reduce the capacity that the driver has to control the cars movement with. The primary task list is relatively complete, even if there are possible additions such as the adaptive cruise control or automated parking in newer cars.

The secondary tasks aid the driver in the driving process and contribute to the safety of the driver, the passengers, secondary users and the surrounding environment.

Tertiary task are not directly related to the process of driving, but may still be desired for comfort, safety or entertainment reasons.

### 3.5.1 Filtering for Concept Development

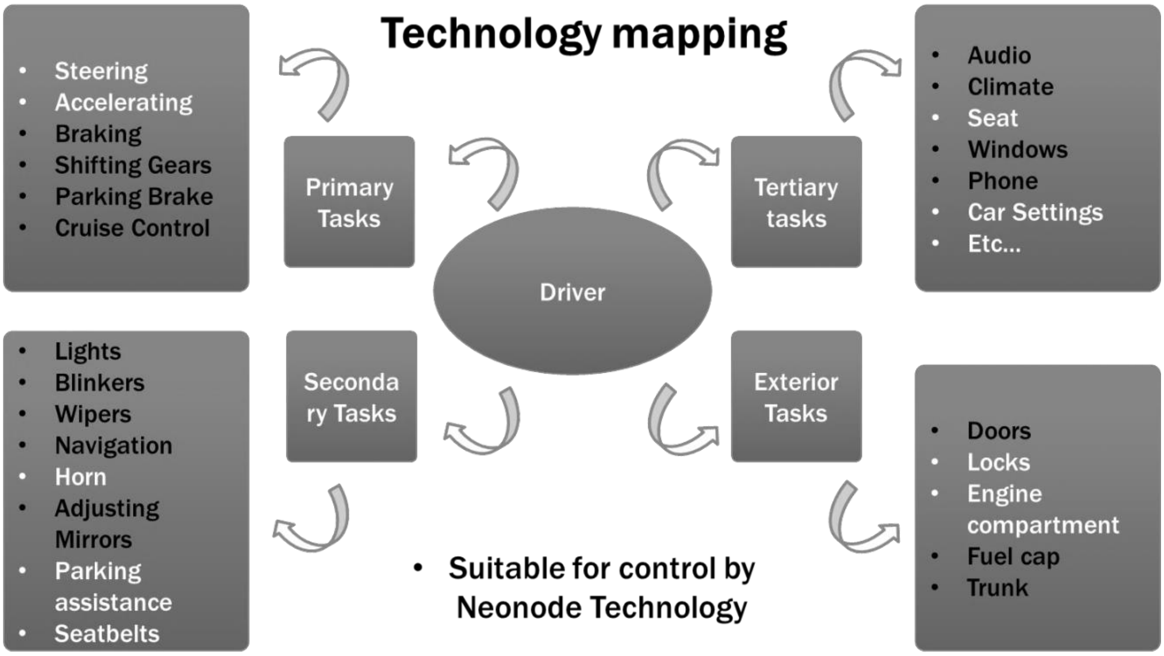
Before developing concepts on how to control the different functions using Neonode technology, the list was reviewed and some of the less promising functions were eliminated (see Figure 12).

Steering and accelerating were deemed to be so heavily standardized that any modifications could overthrow the realism of the concept. Seatbelts are very mechanical solutions that much like the signal horn is very standardized. Parking assistance already uses proximity sensors why such an implementation would be on a different level than this project handles. The seats could very well be controlled by sensors, but were eliminated due to the difficulty of grouping such a function with other functionality.

“Car settings” is not a specific task, but rather a collection of different tertiary functions that concepts should be developed induvidually for. This group of functions was eliminated because it seemed to extensive to do a proper job of defining and developing concepts for each function, but with only insignificant increases to the marginal utility.

Initially, the exterior task were not to be considered at all, but during the gesture sketching, some interesting concepts were discovered, why they have been included in the report.

**Figure 12: Selection for early concept development**



# 4 Early Concept Development

## 4.1 Early Sketches

A number of idea concepts were generated through Gesture sketching and video was recorded. The concepts below are grouped according to the group of functions to which they belong (see Figure 12 in 3.5). The concepts are based on the theory and the design guidelines when possible.

### 4.1.1 Primary Task Concepts

**Cruise control**

Figure 13: Screenshot from gesture sketching

The cruise control is activated by sweeping upwards with the right foot that usually controls the accelerator. The motion is tracked by proximity sensors on the pedal or on the panel next to the pedal. This coheres with the guidelines that devices are grouped after functionality. It is also a control that does not require visual input to be operated.

**Anticipate break**

Something already used in the automotive industry is panic break functionality. This means that a car starts to break even before the brake pedal is pressed. The Neonode technology could track the movement of the right foot using proximity and control the speed of the car accordingly. This functionality is executed without adding any strain to the driver and is a way of tracking driver intention.

**Gear shifting**

Figure 14: Screenshot from gesture sketching

When shifting gears, it could be useful to have a gear shifting indicator handy. This could be achieved by installing proximity sensors in the gearstick and when the stick is grasped, a gear-shifting indicator appears in a Head-Up-Display. This relates to guidelines #1-4 and #10. It should be noted that the driver grasps the gearstick in different ways depending on which gear he/she is about to shift to. This intention could be tracked and utilized in different applications.

**Parking break**

The parking break could be integrated into a touch surface with other functionalities and controlled by a gesture in order to reduce the number of controls in the driver environment. This could cut costs and leave room for other functionality.

### 4.1.2 Secondary Task Concepts

**Blinkers**

The blinkers are controlled by stalks on the steering wheel in most cars today. These stalks could be replaced by proximity sensors. The sensors could be swept up and down to give turn signals left and right, pressed and swept back and forth for other functionality related to the lights. These motions follow the guideline #7 that the functionality should be similar to other familiar systems.

**Windscreen wipers**

Figure 15: Screenshot from gesture sketching

Figure 16: Screenshot from gesture sketching

Windscreen wipers can be controlled by proximity sensors similar to the blinkers and activated by a push. The speed can then be controlled by a proximity slider on the steering wheel. For a single wipe, the wipers could be activated by a swiping motion in front of the windshield, tracked by proximity sensors on top of the steering wheel. This is in coherence with guideline #7.

**Rearview mirrors**

Controlling the rear-view mirrors could be done automatically by tracking the position of the driver's head with proximity sensors and adjusting the rear view mirrors accordingly. The angles of the rear view mirrors could also be controlled using a "Stargate" type application that can track angles in two dimensions.

**Navigation**

Figure 17: Screenshot from gesture sketching

Input of, for example GPS navigation destinations could be done by textual input at the steering wheel, using the finger as a stylus. GPS navigation is now integrated in cars and textual input is an element that is interesting in many applications. This design application is in accordance with guideline #1.

### 4.1.3 Tertiary Task Concepts

**Audio system volume**

Figure 18: Screenshot from gesture sketching

The volume of the audio system could be controlled using a slider located by the audio module. This is in accordance with the guideline for grouping controls according to functionality.

**Climate flow control**

The flow from the fans could be controlled by a slider above the outflow of the fans. This in in accordance with the guideline for grouping according to functionality but also provides multimodal feedback in the form of feeling the airflow on your palm.

**Windows**

The windows and the trunk could either be controlled using sliders on a mediating representation of the car interior, for example a square hole, or directly by touching the windows. The first has mainly functional and economic advantages compared to an electromechanical solution. The latter has distinct cognitive advantages through being in line with for example guideline #8 and #12.

**Phone (thumb app)**

Figure 19: Screenshot from gesture sketching

Many of today's cars have easy-to-access buttons on the steering wheel that make it easier for the driver to handle e.g. phone calls while driving. These buttons could be replaced with small touch screens with the phone functionality only active upon indication or when someone is calling in. These screens can be synchronized with the Head-Up-Display. This application is supported by guidelines #1, #2 and #4.

### 4.1.4 Exterior Tasks

**Doors**

Doors could be opened automatically by an outward gesture at the back edge of the door, close to the position of the door handle. The door would then open until it detects an obstacle in its vicinity, avoiding collision with for example a car parked next to it. This could be solved using proximity detection and is in line with the #5, #7, #8, #11 and #12 design guidelines for good controls.

**Fuel cap**

The fuel cap could open automatically after having tracked a specified gesture, such as a password-symbol (such as the one used to unlock some smartphones), using proximity sensors. This would allow for touch free interaction with potentially dirty surfaces. It is also in line with the physical strain guideline #12

**Trunk**

Opening the trunk could be done using a sweeping gesture with the leg in case hands are occupied carrying luggage. This could be tracked with proximity sensors for touch-free interaction.

## 4.2 Promising Areas

Based on the concepts, the initial study and a presentation of the generated concepts, four areas were identified as interesting for further development.

### 4.2.1 Thumb Interaction

The concept for answering the phone with a use of the Head-Up-Display and the right thumb seems promising from the standpoint of human factors and circumstance dependant interfaces. The interface could be developed further to cover a wide range of functionalities and has the possibility to be operated even when the steering-wheel is turned. Furthermore, Neonode has a history of creating innovative solutions for thumb-interaction on small screens which makes concepts in this area trustworthy. These concepts have possible applications in for example the cruise control, audio, climate, lights and phone handling tasks.

### 4.2.2 Haptic Feedback

One of the main reasons that touch interaction has not yet been widely introduced in cars is that it normally lacks the haptic feedback that is important for non-visual operation. If a technology is aiming to become dominant in the industry, it is important that it is compatible with solutions for haptic feedback. In a recent master thesis at Industrial Design Engineering (Gaspar 2011), the "surface texture changing"- technology provided by the Finnish company Senseg was identified as the most promising technology from a human factors standpoint. It would be interesting to see if this type of technology could be integrated in a future concept. It could be implemented into the same functions as the thumb interaction concept or in any other touchscreen.

### 4.2.3 Touch on Panels

Looking at the design of many car interiors, curved panels make up a large quantity of the accessible surfaces in the driver environment. Here, Neonode technology in its basic setup faces a challenge, and it would be interesting to experiment with different setups to enable touch on convex surfaces with the Neonode Technology. From the Technology study, two viable options were obtained.

The first option uses two proximity lists set up opposite to one and other, spanning a curved surface. The Y-coordinate is then derived from the shadowing of the PDs, while the X-coordinate is calculated using the difference in reflection between the two lists. This solution can also integrate coloured diodes to give the lists a visual indication of when the touch is activated that can be perceived by the peripheral vision.

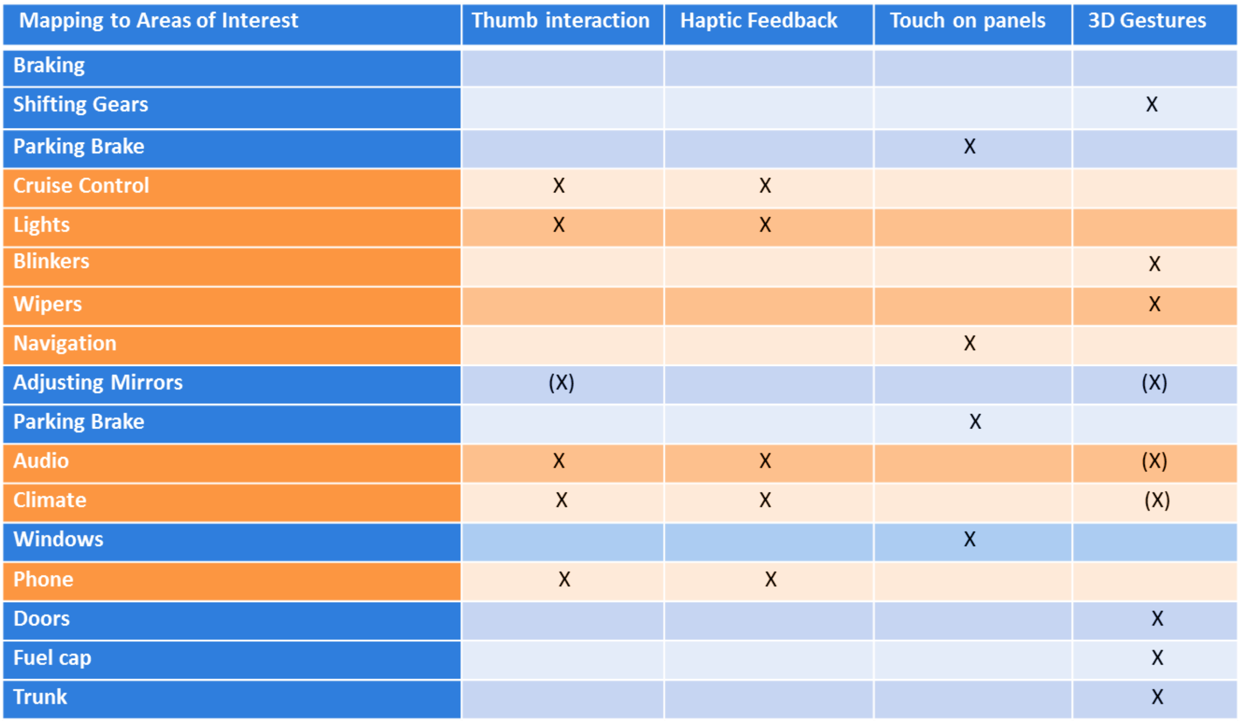
The second setup is the 3D surface touch that could be obtained by placing proximity detectors (LED and PDs) under a semi-transparent surface, thus enabling touch on the surface and creating a 3-dimensional interaction space over the surface. This could for example be implemented forgiving textual input on the steering wheel for navigation tasks.

### 4.2.4 3-Dimensional Gesture Spaces

The previously mentioned 3-dimensional interaction space is the last area that was identified as particularly interesting for the future development. Proximity detection can be used to track a variety of different gestures, both on and in the vicinity of surfaces. The technology may not always be able to track the same variety of gestures or have the same reach as a camera based technology, but it could quite possibly be a much more rugged and inexpensive solution. This could be applied for controlling the blinkers and the windscreen wipers.

If the different concepts are mapped to the areas of interest as in *Figure 20*, it is easy to see that a selection can be which demonstrates all these interesting areas in in one single final concept.

**Figure 20: Mapping to areas of interest**



| Mapping to Areas of Interest | Thumb interaction | Haptic Feedback | Touch on panels | 3D Gestures |
|---|---|---|---|---|
| Braking | | | | |
| Shifting Gears | | | | X |
| Parking Brake | | | X | |
| Cruise Control | X | X | | |
| Lights | X | X | | |
| Blinkers | | | | X |
| Wipers | | | | X |
| Navigation | | | X | |
| Adjusting Mirrors | (X) | | | (X) |
| Parking Brake | | | X | |
| Audio | X | X | | (X) |
| Climate | X | X | | (X) |
| Windows | | | X | |
| Phone | X | X | | |
| Doors | | | | X |
| Fuel cap | | | | X |
| Trunk | | | | X |

## 4.3 Functionality to Concept

Figure 21 illustrates the results of the concept selection process for development into the final concept that was conducted in connection with the intermediate presentation.

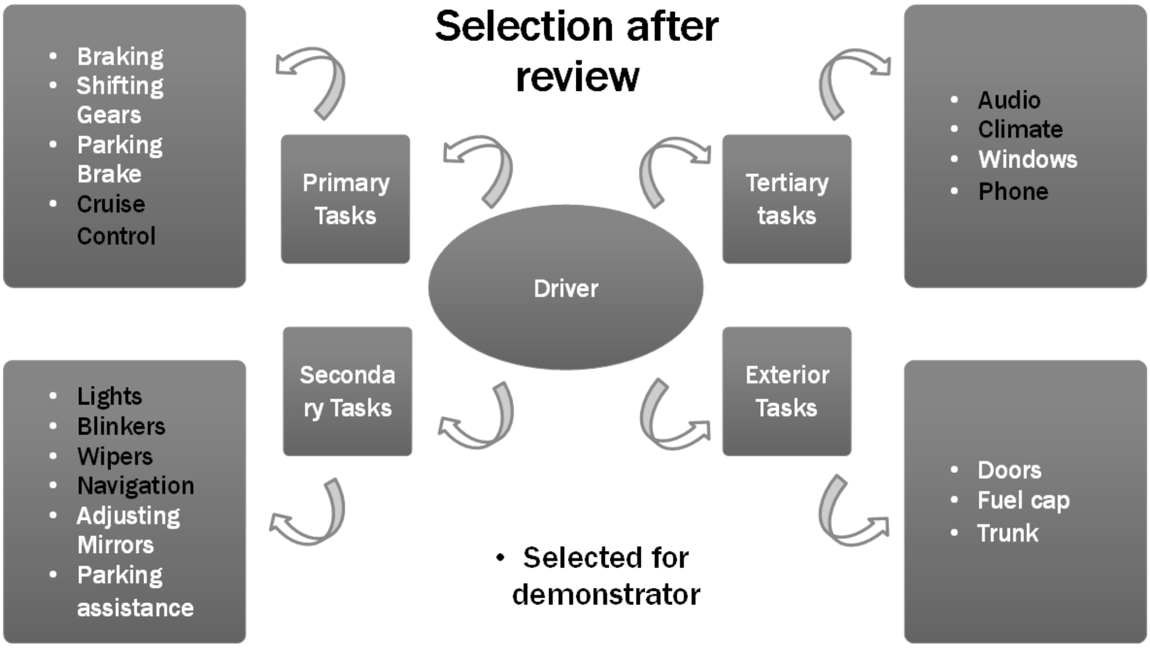
It was suggested that the range of the concepts presented was too wide to be completed within the thesis project and that tasks related to the exterior of the car would not have anything to contribute to improving human factors in the driver environment. Furthermore, the mapping of the driver visual field and the layout of the devices in the driver environment (Figure 8, chapter 3.1.9) suggest that the most interesting concepts from a human factors perspective are those related to moving functionality from the less favourable position at the center stack to more suitable positions at the HUD, the HDD and the steering wheel, while maintaining a reasonable amount of cognitive load on the driver.

It is possible to include a multitude of different functions in a final concept, but for the selection of functions seen in *Figure 21* to be housed in the vicinity of the steering wheel, HDD and HUD respectively, it could have the following features:

**Track pad-controlled Head-Down-Display**

The need for textual input and easier interaction with an on-board computer could be resolved by using a solution that features a touch area on the mid-section of the steering wheel that is connected to the Head-Down-display. Traditional Head-Down-Displays with actual gauges are today often replaced by high resolution monitors. This enables active and interactable content. The trackpad could also be handwriting-input enabled and demonstrates a principle for which Neonode technology can be used for touch on curved panels.

**Figure 21: Selection of concepts for further development**



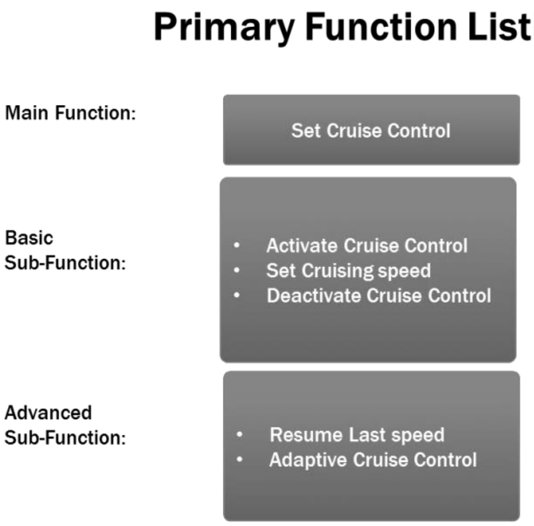
### Thumb-screens mirrored in Head-Up-Display

One concept found very promising from the early concept development stage was the thumbscreen concept with connections to the Head-Up-Display. This set up would allow the driver to interact with the in-car system without moving the hands away from the steering wheel and without averting the gaze from the traffic scene. If haptic feedback is included in the thumbscreens, this function covers two of the defined interesting areas for future development.

### 3-Dimensional proximity stalks.

In the early concept development stage, there were many secondary task concepts identified as suitable for control by Neonode technology, many of them today controlled by the steering wheel stalks.

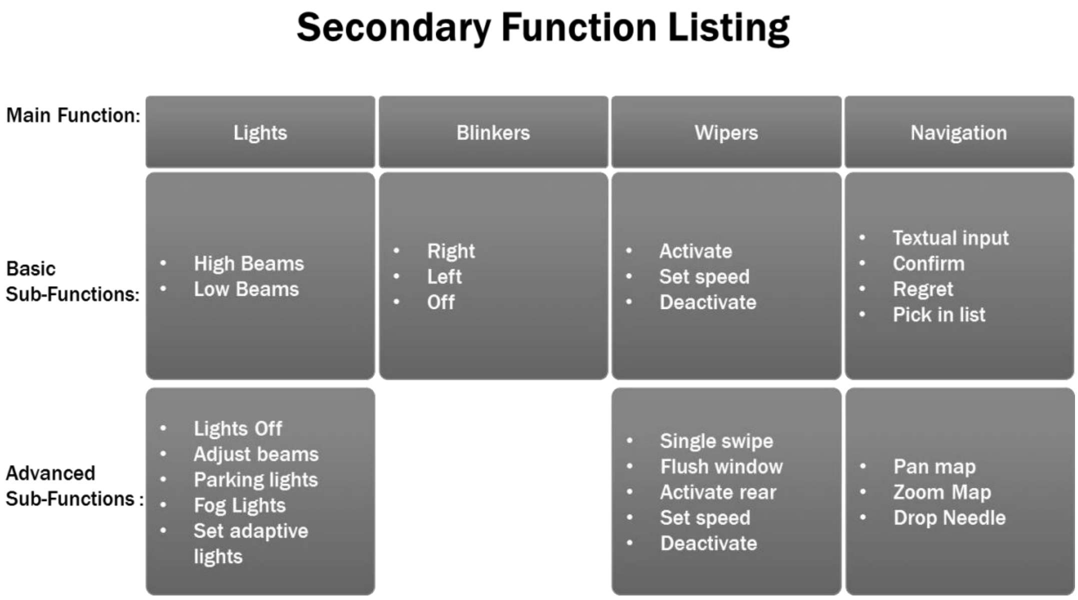
These tasks are mainly activated by sweeping gestures that manipulate the stalks into new positions. These gestures could just as well be tracked by clusters of proximity sensors. This implementation would demonstrate that gesture control is something already present in cars, and that gestures can be tracked by optical sensors as well as mechanical ones.



**Primary Function Listing**

| | |
|---|---|
| Main Function: | Set Cruise Control |
| Basic Sub-Function: | • Activate Cruise Control<br>• Set Cruising speed<br>• Deactivate Cruise Control |
| Advanced Sub-Function: | • Resume Last speed<br>• Adaptive Cruise Control |

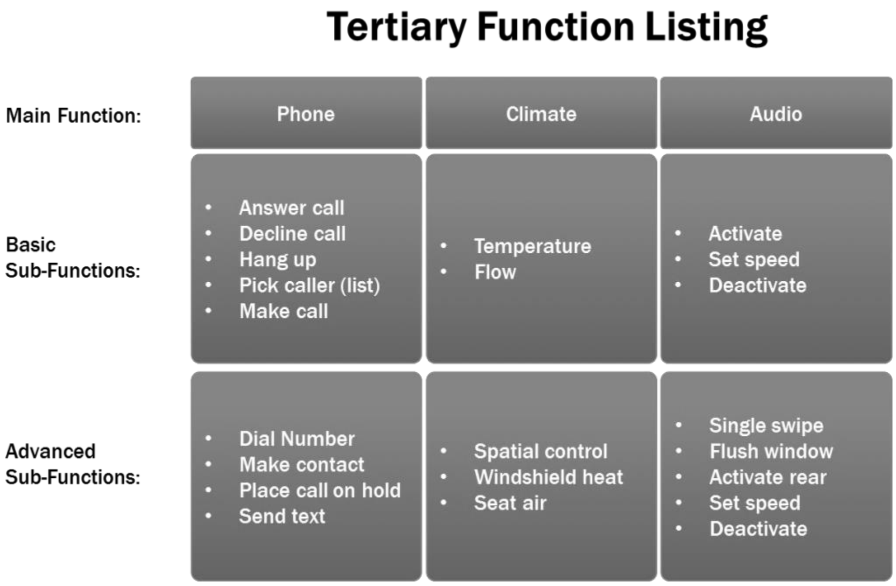
Figure 22: List of primary functions and sub-functions



**Secondary Function Listing**

| Main Function: | Lights | Blinkers | Wipers | Navigation |
|---|---|---|---|---|
| Basic Sub-Functions: | • High Beams<br>• Low Beams | • Right<br>• Left<br>• Off | • Activate<br>• Set speed<br>• Deactivate | • Textual input<br>• Confirm<br>• Regret<br>• Pick in list |
| Advanced Sub-Functions : | • Lights Off<br>• Adjust beams<br>• Parking lights<br>• Fog Lights<br>• Set adaptive lights | | • Single swipe<br>• Flush window<br>• Activate rear<br>• Set speed<br>• Deactivate | • Pan map<br>• Zoom Map<br>• Drop Needle |

Figure 23: List of secondary functions and sub-functions



**Tertiary Function Listing**

| Main Function: | Phone | Climate | Audio |
|---|---|---|---|
| Basic Sub-Functions: | • Answer call<br>• Decline call<br>• Hang up<br>• Pick caller (list)<br>• Make call | • Temperature<br>• Flow | • Activate<br>• Set speed<br>• Deactivate |
| Advanced Sub-Functions: | • Dial Number<br>• Make contact<br>• Place call on hold<br>• Send text | • Spatial control<br>• Windshield heat<br>• Seat air | • Single swipe<br>• Flush window<br>• Activate rear<br>• Set speed<br>• Deactivate |

Figure 24: List of tertiary functions and sub-functions

# 5 Final Concept Development

## 5.1 GUIs

The functionality that was to be included in the GUI (Graphical User Interface) was split into groups and sub-functions for each function were identified. (See Figures 22, 23 and 24)

It was deemed that the GUI for the testing should be able to show at last basic functionality, as well as feature most standard displays, such as speedometer and fuel-gauge etc. White on black was chosen for highest possible contrast if the Head-Up-Display was to be projected on the windshield. Since time was limited, graphical elements were kept as simple as possible for the GUI not to look like an attempt at a finished product but as a feasability test of a layout of functions.

For the development of these GUIs, a set of icons was already available from a previous project that Neonode had done and could be utilized to make up parts of also this GUI.

### Head-Down-Display (HDD)

The Head-Down-Display (Figure 25) features an overview of the car's status, various settings, and a navigation system. All these functions are fairly complicated to operate and subsequently require a substantial amount of the user's attention resources to operate. They are therefore suitable to operate only when the driving situation is not demanding or when the car is stationary. Hence, the Head-Down-Display was considered a suitable location for such functions.

### Head-Up-Display (HUD)

The Head-Up-Display features a cruise control GUI, a simple climate control panel, a music player and a telephone application as well as information

Figure 25: Head-Down-Display GUI

about speed and simple navigation information (Figure 26) that is often found in a Head-Up-Display solutions currently on the market. The functionality is sparse with only the most important functions incorporated in order to reduce the visual and cognitive load on the driver. All functions are however functions that are often used while the driving situation is more or less demanding. It should therefore be possible to operate them without averting the gaze from the driving scene.

Figure 26: Head-Up-Display GUI

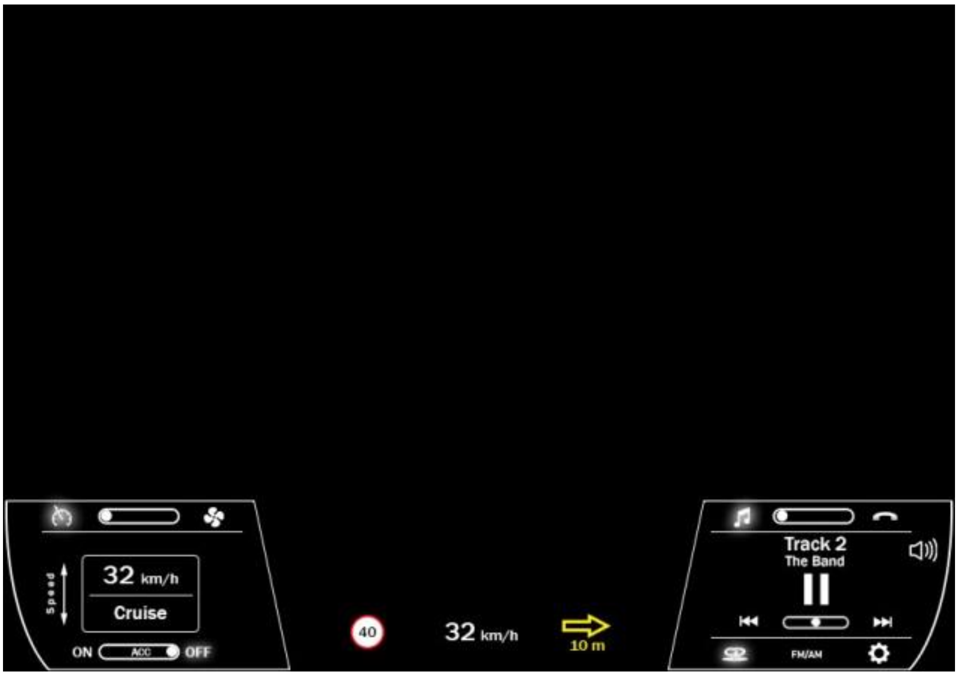


Figure 27: Various sketches from different stages in the design process

## 5.2 Physical Design

Some of the early design concepts (Figure 27) do not look much like steering wheels in today's cars, but because the final product may be developed into a demonstrator, showing how the Neonode technology could be implemented in cars that are arriving on the market within the next couple of years, conventionality was not necessarily seen as a negative characteristic.

The final result (Figure 28) is a 4-spoke steering wheel with some unconventional design features that highlight the functionality of the steering wheel. The most prominent design feature is the rift between the two bottom spokes of the steering wheel. The cut-out indicates that the space between spokes is an area that can recognize touch or gesture interaction. The space also has the effect that the steering wheel will be more comfortable to operate with progressive steering rather than conventional steering so that the wheel will not have to be turned many revolutions.

The mid-section is slightly sunk in between the elongations of the two bottom spokes and demonstrates the principle where Neonode technology can be used to add touch interaction to any one-dimensionally curved surface. The mid-section is flanked by two opposing proximity arrays providing X- and Y-direction coordinates for any touch points on the touch surface.

Figure 28: Perspective rendering of the final concept

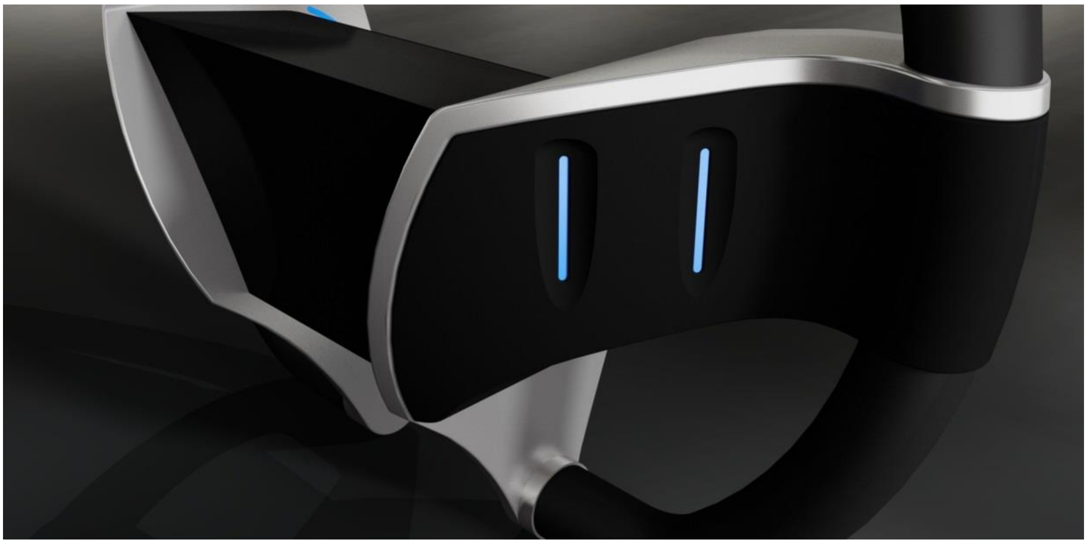
The screens on the top spokes of the steering-wheel refer to the Neonode brand history. In 2002 Neonode introduced one of the first touchscreen phones that used infrared technology for control by the thumb, through tapping and sliding gestures. The phone utilized the edges around the screen by using the light guide as a haptic indication of the fingers' position on the screen. This reduced the demand for visual navigation in the system. As Neonode is moving into the automotive segment, the haptic indications and the less visual navigation will be even more important than it currently is for mobile devices. The two 3.5-inch screens (Figure 30) are representations of this heritage and are positioned to provide comfortable access to the entire screen area. The screens are positioned on volumes that bind the elements of the steering wheel together while containing all the electrical components.

Figure 29: Front detail-view rendering of the final concept

On the back of these volumes, 3D-proximity replacements for the steering wheel stalks are placed (Figure 30). They are placed on a convenient distance from the driver's fingers so that the driver will have to extend his/her fingers slightly towards the centre of the steering wheel in order to avoid accidental activation. The angle and range of the sensors has to be adapted to the surrounding environment so that they are only activated by hands making gestures and not when the steering wheel is turned. The sensors are surrounded by groves that provide haptic feedback and guidance when they are operated using crude gestures.

The blue plastic that covers the sensors (see Figure 29-30) is intended to distinctly highlight where the technology is placed and indicate which areas are touch enabled. If a backlight is added behind the plastic covers, the sensors will be visible in the dark. If the backlight increases in luminance in a corresponding position to a touch point, it could describe to users how the technology works.

**Figure 30: Back detail-view rendering of the final concept**



## 5.3 Formative Evaluation

The formative evaluation resulted in the following changes to the system:

- The HDD top menu icons were changed from rotating to fixed positions.
- Symbols were added to indicate the functionality of the proximity replacements for steering wheel stalks.
- Only one type of arrows was used throughout the whole system.
- Haptic indications for the HDD top menu choices were added on the mid-section of the steering wheel.
- Added a background to the HDD top menu.
- Wiper speed control was moved to the front of the steering wheel.
- The indication of the current menu choice in the HUD top menu was changed.

# 6. Validation

To validate the result a Kano Analysis survey and a benchmark usability test were executed.

## 6.1 Kano Analysis

The questionnaire had 15 respondents and evaluated the attractiveness of the features Head-Up-Display, touchscreens and gesture control and compared these to the more standard solutions of media players and GPS navigation systems.

The result was that the features HUD, gesture control and touchscreens have strong exciter-characteristics when compared to the features GPS Navigation System and Media Player. There was however a bit of uncertainty to whether or not the functions were useful. Several of the respondents had no previous experience with such functions, and could not state that they cared about the implementation without any experience from using it.

The data the graphs (see Figure 31) are based on can be found in *Appendix B – Kano Model Results*. Note that the graphs have been plotted to give a visual comparison of the functions and does not claim to be mathematically correct but give an indication of the exciter characteristics of the features

.

**Figure 31: Plot of the result of the Kano analysis**

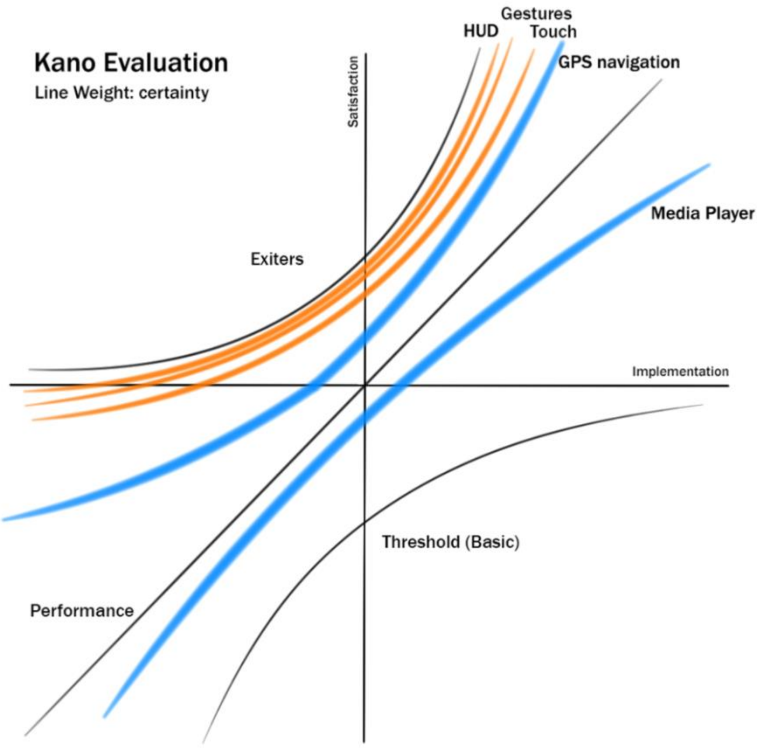


Figure 32: The usability test-environment

## 6.2 Benchmark Usability Test

### Summary

Benchmark tests were carried out in order to evaluate the performance of the prototype compared to solutions out on the market today from a usability perspective. On the road usability tests were conducted with a selection of users in a total of 28 test runs. The experiment used Volvo V60 that was modified in between tests to resemble the prototype solution. The results show a decrease of the error rate when using the prototype solution rather than the industry benchmark, and the qualitative data also shows that the user satisfaction is greater using the prototype system.

### Implementation

The benchmark system chosen to evaluate the prototype system against was a Volvo V60 year model 2011. The chosen car is used by the company Sunfleet as a carpool car in Gothenburg. It was seen as a suitable car because it is relatively new and also a car that is used by different people every day, why the requirement for usability, especially among first time users, ought to be high. Being a Volvo, which is the most common car in Sweden as well as a car used in many driving schools, it ought to set the bar high as a benchmark solution. The modifications made to the car prior to the tests were that an iPhone was mounted on the car center stack and paired with the car infotainment system to enable in-car calling. Since the car lacked an on-board GPS, the iPhone was also used for the navigation task through an application called Wayz.

For testing the prototype system, cardboard and paper cut-outs were added to the steering wheel to make it resemble the concept steering wheel (see Figure 32). The same LCD screen setup that was used in the formative evaluation was used for the Head-Down-Display, but the Head-Up-Display pico-projector had to be replaced with a turnable cardboard representation because of problems with the power supply. (See Appendix C for a detailed description of the prototype.)

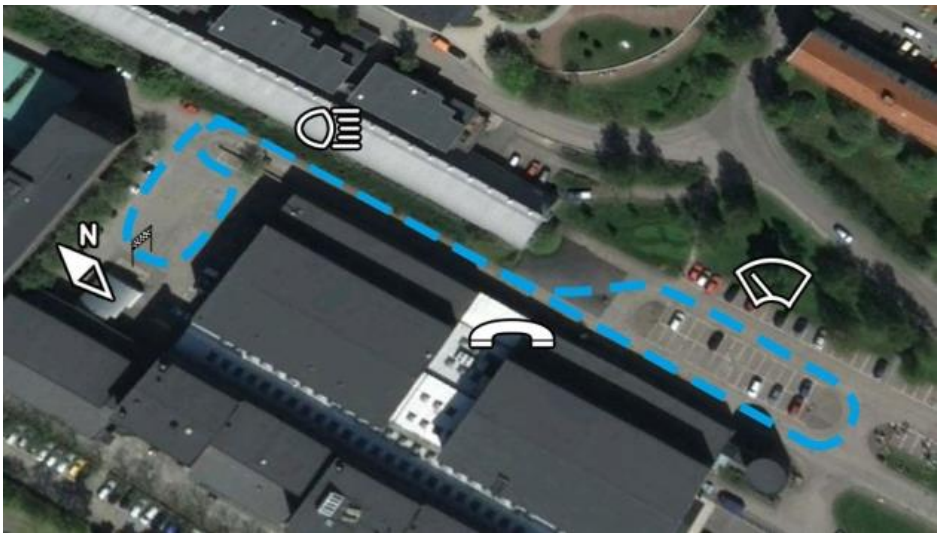


Figure 33: The layout of the test-course

There were in total 28 test runs carried out, 14 with the benchmark system and 14 with the prototype system. The 7 test subjects carried out 2 test runs with each setup. The subjects were aged between 19 and 32. The tests were performed two times in a row with each system and test-subject, then the set up was changed and two tests were performed with the new set up. The order of the prototype/benchmark tests was alternated between the test-runs to compensate for any learning effects. Four of the six tasks from the formative Evaluation were re-used in the test.

1. Navigation:
   Add new destination
2. Wipers:
   Activate wipers at highest speed
   Shut of wipers
3. Lights:
   Activate high beams
   Deactivate high beams
4. **Telephone:**
   Call contact.

This choice was partly because the tests would have been very lengthy with double the amount of runs (both benchmark and prototype), and partly because there was almost no difference between the results in the formative evaluation for the 3 last tasks, all using the thumbscreen/HUD set up.

The test site chosen was a closed off parking lot (see Figure 33). When the test subjects showed up on the test site, they were given the questionnaire for the Kano evaluation and were asked to fill it in. When this was completed, they were given the instructions that they would be given 4 different tasks that they had to carry out while driving. They were also given some basic instructions about the thought functionality of the prototype; basically that the cardboard pieces were representations of touch areas and that the two on the steering wheel were mapped to the HUD and that there were proximity sensors on the back of the steering wheel (see instructions in Swedish in Appendix D – Usability Protocol). The test subjects executed the first task while stationary and the three following tasks while the

Figure 34: View From one of the CCTV cameras during test

car was moving slowly on first gear around the test course.

Before the test, the minimum number of actions was checked. During the test, the number of errors while using the systems and the number of times the user took his/her eyes off the road (more than approx. 15 degrees) during the telephone task for more than 1.5 seconds were measured. (for complete protocol see Appendix D) The minimum number of actions should give an indication to the efficiency of the respective HMI designs, while the number of errors would provide a good measurement of guessability and overall usability. Doing a second run may indicate the learnability of the design and the experienced user performance of the system, while the eyes off road measurement limits originates from the results of the literature study and is a driving-specific measurement.

The test runs were documented with a CCTV setup in the car that both showed the test subject (see figure 34) and the traffic scene in front of the car. This was used primarily to check the eyes off road time measurement. The errors were entered into the protocol by the moderator during the test.

**Results**

The theoretical minimum number of actions (see Figure 37) needed to

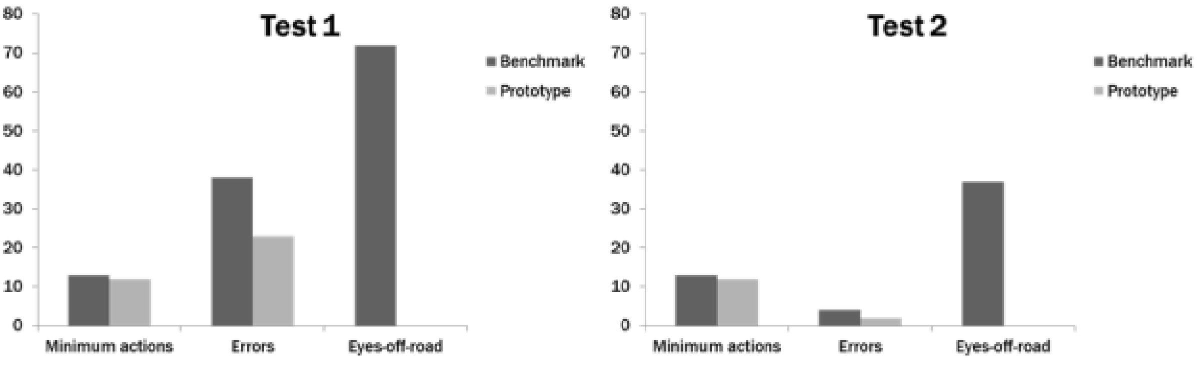


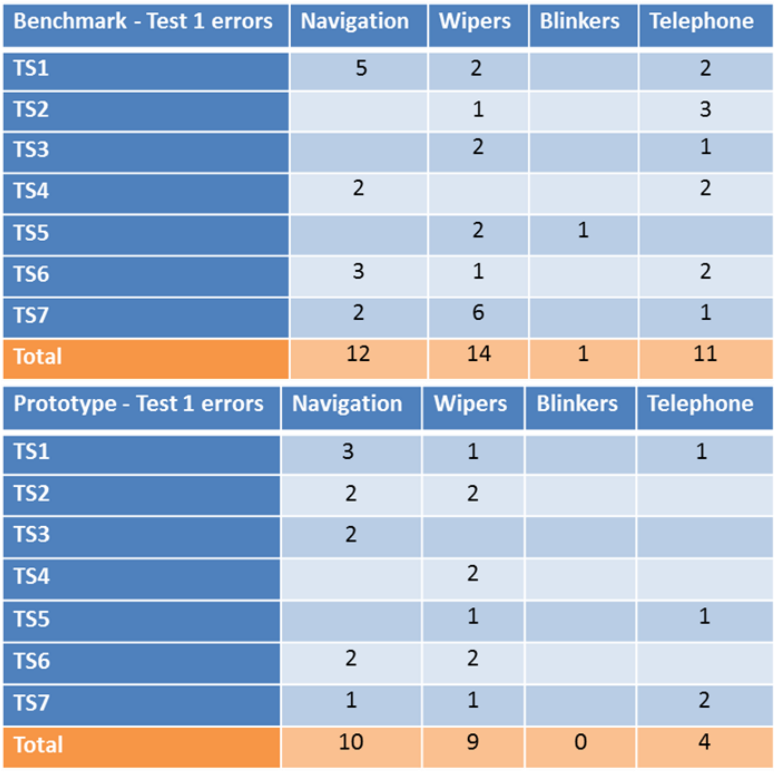
Figure 37: Plot of the measurements from test 1 and 2

execute all the four tasks did not differ much between the two systems (12 for the benchmark and 11 for the prototype).

When looking at the total number of interaction errors during the first test run, the total number of errors for the benchmark solution is 38, while the total number of errors for the prototype is 23. Looking at the distribution of errors over the test subjects (see Figure 35), the benchmark has an even distribution over the tasks except for blinkers that only contributed with one error. For the prototype, the majority of errors were conducted in the navigation and wiper tasks respectively (see Figure 36). It should be noted that during the windscreen wiper test for the benchmark (14 errors), one slightly stressed test subject accounted for almost half (6) of the errors by repeatedly activating the blinkers and windscreen washer fluid, why this figure may be slightly bloated.

The major advantage for the prototype concerned the telephone-task where only four errors were conducted using the prototype HUD based setup compared to eleven for the traditional setup. Several test subjects expressed their liking for this particular solution and stated that they would prefer such a system to the center stack mounted system used in the benchmark design.  Two of the subjects even pulled over and stopped the car while doing the telephone-task using the benchmark system because they did not feel that is was safe to operate. Regarding the two other functionalities, the results were mixed. None of the test subjects expressed any disliking to any of the systems after

**Figure 35: Errors distributed over test subjects**



| Benchmark - Test 1 errors | Navigation | Wipers | Blinkers | Telephone |
|---|---|---|---|---|
| TS1 | 5 | 2 | | 2 |
| TS2 | | 1 | | 3 |
| TS3 | | 2 | | 1 |
| TS4 | 2 | | | 2 |
| TS5 | | 2 | 1 | |
| TS6 | 3 | 1 | | 2 |
| TS7 | 2 | 6 | | 1 |
| Total | 12 | 14 | 1 | 11 |

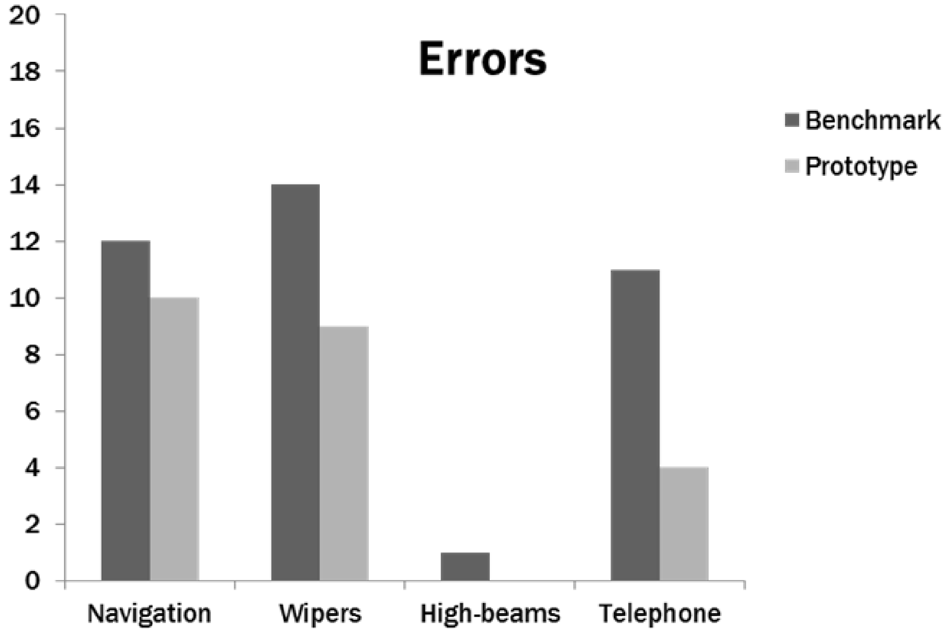
| Prototype - Test 1 errors | Navigation | Wipers | Blinkers | Telephone |
|---|---|---|---|---|
| TS1 | 3 | 1 | | 1 |
| TS2 | 2 | 2 | | |
| TS3 | 2 | | | |
| TS4 | | 2 | | |
| TS5 | | 1 | | 1 |
| TS6 | 2 | 2 | | |
| TS7 | 1 | 1 | | 2 |
| Total | 10 | 9 | 0 | 4 |

understanding how they worked, but there was an element of doubt as to how the mock-up track pad was connected to the Head-Down-Display. This was, according to some of the test subjects, because there was no feedback built in to in the system. The users expressed difficulties in finding clues on to operate the 3D proximity stalks; clearer indications were suggested.

When doing run number two with both solutions, the error rate dropped drastically with only four errors for the benchmark system and two errors for the prototype.

The most distinguishable result is the measurement on how many times the test-subjects took their eyes off the road for more than 1.5 seconds. During the first run, a total of 72 times was recorded for the benchmark and during the second run, the number was 38. The prototype solution resulted in no long glances away from the traffic scene in any of the test runs.

**Figure 36: Detailed plot of the errors in Test 1**



# 7. Discussion

## 7.1 Validation

Even if the validation gave clear indications that the prototype in many areas has advantages over the traditional systems, there are some areas that need further investigation in order to be able to draw definite conclusions. Firstly, comparing the test result between a crude prototype that lacks the normal feedback from the system and a well-tested fully functional solution may have contributed to errors in measurement. Finished solutions usually perform better in some areas, but the risk of making follow up-errors in a system that has more of possible actions to execute is often greater than in serial-flow prototype solution specifically designed to handle the functionality to be tested.

With only seven test subjects, the sample from the benchmark tests is too small to draw conclusions based on the quantifications of the results. One should as a suggestion look at the qualitative aspects during the tests and see if they support or go against the results. In the case of the Head-Up-Display/thumbscreen solution, the comments regarding the functionality were unanimously positive, but more indecisive regarding the two other suggested functionalities.

The Windscreen task showed surprisingly poor performance in regards to the simple nature and clear description of the task. The performance was rather poor in the prototype system but most notably also in the heavily standardized benchmark-system. This probably has an explanation in the concealed position of the controls and lack of indications in the prototype system. For the benchmark system the poor result is explained by one individual user's exceptionally poor performance and the poor feedback regarding the status (set speed of windscreen wipers) that the system provides. Both systems could probably perform much better with a better mapping to standard guidelines for interaction design. Gesture control in cars could be feasible if easy-to-understand icons were developed.

## 7.2 Results

The results correspond well to the initial goals of the project.

The user experience suffers slightly from the very sparsely designed graphical user interface. It would be beneficial for the general impression of the demonstrator to have a more finished and well-designed graphical user interface.  Even if the mock-up GUI well serves it's purpose for evaluating the possible capacity of the functionality, a more finished and better GUI would make it easier to convince potential customers about the feasibility of integrating this type of interaction technology in the next generation of cars.

When it comes to the physical design of the concept solution, it has been pointed out that the final design is not entirely realistic to implement in a modern car because of regulations that state that possible impact-zones in the driver environment need to have a certain impact area to absord the force at a crash and no sharp edger or angles facing the driver, even with the use of an airbag. It is however nothing that has an impact on the feasibility of the concept, but it may be wise to produce a new physical design in order to demonstrate that the technology is compatible also with these design regulations.

## 7.3 Methods and Implementation

During the project, a handful of methods were used to collect and analyse data as well as develop concepts and evaluate them. Early on, there was a large focus on understanding the theoretical framework that is quite vast and complicated compared to many other development projects that the author has been involved in. It was also decided early on to do an evaluation of a concept against a benchmark in order to achieve a result that gave a clear indication to whether or not the technology was suitable for use in a driving environment. This was accomplished within the project, but did not leave time to create multiple concept candidates that could be evaluated against each other to become a final concept.

If more time had been spent in the concept development stage, it is possible that the final product would have had a better finish. More shapes and different concepts could have been generated and compared to each other.

Also, the project does not feature a list of requirements that the concepts could have been evaluated against. This is due to the complexity of the theoretical background. Deciding which concept would perform better from for example a safety perspective requires extensive testing and is not easily evaluated using estimates in a matrix.

## 7.4 Theory

As previously mentioned the theoretical part of this project was quite extensive and gave a solid foundation on which to base the following concepts. However, there are still some questions left that need to be investigated further in order to be able to evaluate the final concept:

How does the Graphical User Interface and the intended interaction with it affects the driver's visual attention?

Which design guidelines are more important when it comes to the process of driving compared to general usability guidelines?

How should interactable content in the Head-Up-Display be designed to minimize the visual and cognitive load on the driver if the driving situation suddenly becomes increasingly demanding? This looks promising in the final suggestion, but needs a stronger proof of concept.

# 8. Conclusions

The theoretical part of the project summarizes and suggests design guidelines for designing user interfaces for the automotive industry. An important conclusion is that the main driving task is a visual process which makes it particularly important for subsidiary secondary and tertiary tasks to place a low visual load on the driver, something achievable through haptic guidance and feedback as well as general design from a human factors perspective.

The final concept fared well when compared to the benchmark solution. This indicates that continued development and testing should be done.

A final reflection is that it is very hard to separately develop controls and displays for a user interface. For touch applications specifically, this means that hardware and software development need to be tightly interlaced.

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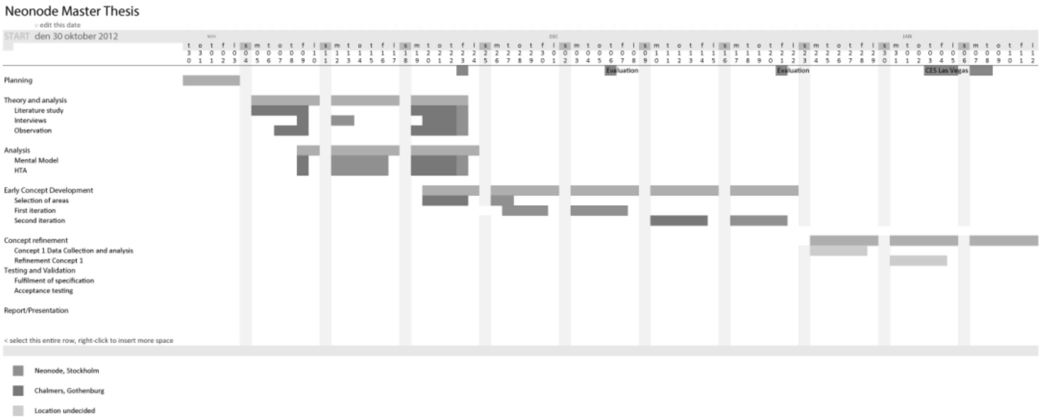
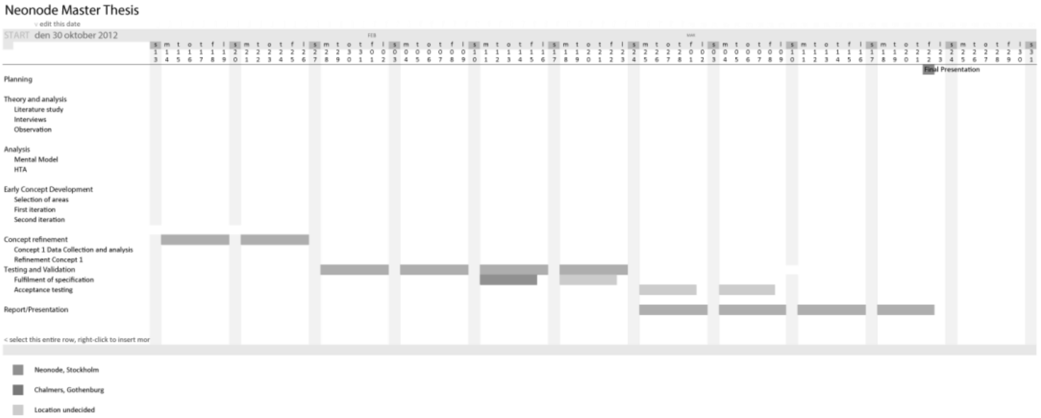
# Appendices

- Appenix A – GANTT –chart
- Appendix B – Kano Model result
- Appendix C – Prototype description
- Appendix D – Usability protocol

# Appendix A – GANNT Chart





## Appendix B – Kano Model Results

Questionnaire (in Swedish)

Frågor:

Ålder:
Körkort : JA / NEJ

Hur skulle du känna dig om din bil var utrustad med:

| | Missnöjd | Neutral (normalt) | Nöjd | Bryr mig inte |
|---|---|---|---|---|
| Mediaspelare | | | | |
| GPS | | | | |
| Head-Up-Display | | | | |
| Geststyrning | | | | |
| Touchpaneler | | | | |

Hur skulle du känna dig om din bil saknade:

| | Missnöjd | Neutral (normalt) | Nöjd | Bryr mig inte |
|---|---|---|---|---|
| Mediaspelare | | | | |
| GPS | | | | |
| Head-Up-Display | | | | |
| Geststyrning | | | | |

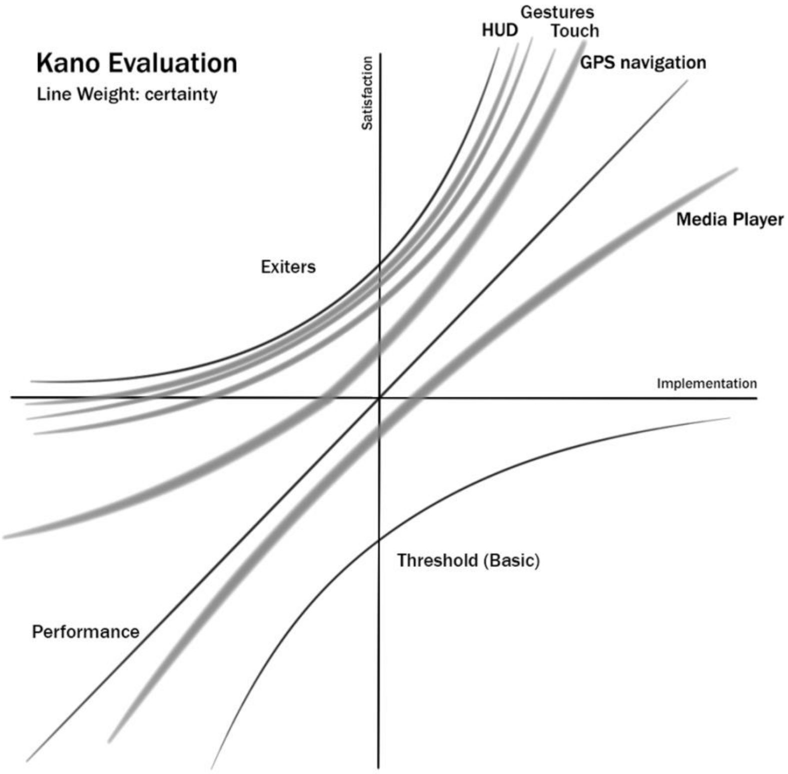
| | | | | |
|---|---|---|---|---|
| Touchpaneler | | | | |

Data:

| Included | missnöjd | neutralt | nöjd | bryr mig inte |
|---|---|---|---|---|
| Media player | | 4 | 10 | 1 |
| GPS | | 1 | 14 | |
| HUD | 1 | 1 | 9 | 4 |
| Gesture control | | 4 | 7 | 2 |
| Touch Panels | | 3 | 10 | 1 |
| Not Included | missnöjd | neutralt | nöjd | bryr mig inte |
| Media player | 13 | 1 | | 1 |
| GPS | 6 | 8 | | 1 |
| HUD | 1 | 5 | 1 | 8 |
| Gesture control | 1 | 7 | | 7 |
| Touch Panels | 2 | 8 | | 5 |

| | basic | performance | exiter | insecurity |
|---|---|---|---|---|
| Media player | 4 | 10 | | 2 |
| GPS | 1 | 6 | 8 | 1 |
| HUD | 1 | | 5 | 12 |
| Gesture control | | 1 | 7 | 9 |
| Touch Panels | | 2 | 8 | 6 |

Visualisation of Data:


Kano Evaluation
Line Weight: certainty
Gestures
HUD
Touch
GPS navigation
Satisfaction
Media Player
Exiters
Implementation
Threshold (Basic)
Performance

## Appendix C – Prototype description

As a prototype, A "Wizard of Oz" - setup in a Volvo V60 was used. The test leader controls the mock-up interface to make it act as similar as possible that it would act in a real situation while the test subject manipulates mock controls.

In this case, a laptop computer was used to power and control the HDD interface. A description of the parts of the mock set up follows:

A: The HUD was emulated by a turnable cardboard mock-up that was placed on top of the instrument panel. This interface was serial and had a small delay.

B: The HDD was emulated by a 13.3 inch LCD screen controlled through a power point presentation powered through a laptop. This gave the possibility to have a more dynamic GUI with only small delays.

C: The thumbscreens were represented by cardboard cutouts attached to the steering wheel on top of the already existing thumb-buttons. The cardboard cut-outs do not display any images, but are similar in shape to the the shape indicated in the HUD display. It is debatable whether or not they would be easier to operate if they displayed the same image

D: A larger representation of a trackpad was attached to the mid -part of the steering wheel. Its placement directly underneath the HDD and its shape indicates that it controls the HDD.

E: Behind the steering wheel, blue strips of paper are attached on both sides of it. They give a slight haptic indication and are meant to simulate the proximity sensors.

F: A blue strip of paper is attached to the right front side of the wheel. In the test, it represents a proximity slider that controls the speed of the windscreen wipers.

G: Two of the CCTV cameras that capture the action in the car. One is facing the front to capture the driving scene and one facing the driver to capture eye-movement.

## Appendix D – Usability Protocol

Protocol (in Swedish):

Instruktioner:
Jag kommer att ge dig några uppgifter som du ska utföra i med hjälp av den här ratten. Alla är vanliga uppgifter som man brukar utföra medan man kör.
Ratten fungerar så att det finns en touchkänslig yta i mitten som är mappad mot Head-down-display Och två touchkänsliga ytor på sidan som är mappade mot Head-up displayen. Det finns också avståndssensorer som känner av rörelse på baksidan av ratten..

Uppgift 1:Lägg till linnegatan 89 som ny destination i navigationssystemet
Uppgift 2: Sätt på vindrutetorkarna på högsta fart och stäng av dem igen.
Uppgift 3 :Sätt på och stäng av helljus.
Uppgift 4: Spela upp "Track 2" från CDn, dra ned volymen
Uppgift 5: Ställ in klimatsystemet på 22 grader.
Uppgift 6: Ring Carl Cahill.

| Test 1 | Handlingar | Felhandlingar | Ledtrådar |
|---|---|---|---|
| #1 | | | |
| #2 | | | |
| #3 | | | |
| #4 | | | |
| #5 | | | |
| #6 | | | |

| Test 2 | Handlingar | Felhandlingar | Ledtrådar |
|---|---|---|---|
| #1 | | | |

| | | | |
|---|---|---|---|
| #2 | | | |
| #3 | | | |
| #4 | | | |
| #5 | | | |
| #6 | | | |

Data:

**Benchmark**

| *Test 1* | | Minimum actions | Errors | Eyes-off-road |
|---|---|---|---|---|
| | Navigation | 5 | 12 | |
| | Wipers | 2 | 14 | |
| | High-beams | 2 | 1 | |
| | Telephone | 4 | 11 | 72 |
| **Sum** | | 13 | 38 | 72 |

| *Test2* | | | | |
|---|---|---|---|---|
| | Navigation | 5 | | |
| | Wipers | 2 | 2 | |
| | High-beams | 2 | | |
| | Telephone | 4 | 2 | 37 |
| **Sum:** | | 13 | 4 | 37 |

**Prototype**

| *Test 1* | | Minimum actions | Errors | Eyes-off-road |
|---|---|---|---|---|
| | 1 | 4 | 10 | |
| | 2 | 3 | 9 | |
| | 3 | 2 | | |
| | 4 | 3 | 4 | |
| **Sum:** | | 12 | 23 | 0 |

| *Test2* | | | | |
|---|---|---|---|---|
| | 1 | 4 | | |
| | 2 | 3 | 2 | |
| | 3 | 2 | | |
| | 4 | 3 | | |
| **Sum:** | | 12 | 2 | 0 |

Visualisation of data: