Real Time Vehicle Diagnostics
Using Head Mounted Displays

by

Gustav Enblom
Hannes Eskebaek
LIU-IDA/LITH-EX-A--15/040--SE
2015-06-09
Master’s Thesis

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Supervisor: Ola Leifler
Examiner: Ahmed Rezine
Abstract

This thesis evaluates how a head mounted display (HMD) can be used to increase usability compared to existing computer programs that are used during maintenance work on vehicles. Problems identified during a case study in a vehicle workshop are first described. As an attempt to solve some of the identified problems a prototype application using a HMD was developed. The prototype application aids the user during troubleshooting of systems on the vehicle by leading the mechanic with textual information and augmented reality (AR). Assessment of the prototype application was done by comparing it to the existing computer program and measuring error rate and time to completion for a predefined task. Usability was also measured using the System Usability Scale. The assessment showed that HMDs can provide higher usability in terms of efficiency and satisfaction. Furthermore, the thesis describes and discusses other possibilities and limitations that usage of HMDs and AR can lead to that were identified both from theory and during implementation.
We would like to thank Scania for being so welcoming and for the opportunity to work on this project. We would like to especially thank Lars Andersson and Alexander Stojcevski at Scania, our supervisor Ola Leifler and our examiner Ahmed Rezine for their guidance and support during the whole project.
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## Definitions

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<td>AR</td>
<td>Augmented Reality. View technique where digital objects are superimposed on the real world</td>
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<td>DTC</td>
<td>Diagnostic Trouble Code. Code stored in an ECU that describes a vehicle fault</td>
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<td>ECU</td>
<td>Electric Control Unit. Embedded system that controls one or several of the electric systems on the vehicle</td>
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<td>GDK</td>
<td>Glass Development Kit. Software Development Kit for creating applications for Google Glass, Glassware</td>
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<td>GG</td>
<td>Google Glass. A Head Mounted Display developed by Google</td>
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<td>HMD</td>
<td>Head Mounted Display. Display device that is worn on the head offering a small display in front of the eyes</td>
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<td>SCOMM</td>
<td>Scania Communication Module. Communication component that connects a VCI with external clients such as PC applications</td>
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<td>SCR</td>
<td>Selective Catalytic Reduction system. Aftertreatment system that lowers the amounts of NOx in the exhaust gas</td>
</tr>
<tr>
<td>SDK</td>
<td>Software Development Kit. Software tool used for creating software applications for a specific platform</td>
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<tr>
<td>SDP3</td>
<td>Scania Diagnos &amp; Programmer 3. PC application used as a tool when conducting vehicle repairs and other maintenance tasks</td>
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**SMAPi**  .Net wrapper in SCOMM that enable .Net applications to use SCOMM functionality

**VCI**  Vehicle Communication Interface. Communication interface that enables connection to the CAN bus on a vehicle
Introduction

Previous studies have shown that Augmented Reality (AR) used together with a head mounted display (HMD) can provide great support during maintenance work [1], [2], [3], [4]. Less knowledge is required since information can instead be presented with the HMD and superimposed, at the right time, into the real world using AR techniques [5].

Scania has, during the last years, developed a module called SCOMM (Scania Communication Module) for connected vehicles, the platform makes it possible to read data from vehicles in real time. This enables mechanics or Scania employees to remotely connect to vehicles. As an extension to this platform Scania wants to integrate AR units to communicate over the wireless channel. Scania sees a lot of potential in AR units and the possibilities they enable, e.g. picture recognition, 3D-rendering and video streaming.

1.1 Purpose

This thesis aims to evaluate if, and how, HMDs can aid mechanics during maintenance work on vehicles. More specifically, the purpose is to examine if HMDs can make maintenance tasks more efficient as well as provide higher satisfaction than existing PC applications. HMDs that are wirelessly connected to the vehicle can present vehicle data such as diagnostic codes and signals to the mechanic without requiring the mechanic to use his hands or move to a computer to get that information.
1. **Introduction**

The vehicle information can also be combined with AR functionality which could increase efficiency even more. This thesis will also result in conclusions on what possibilities and limitations that usage of HMDs can lead to.

1.2 **Research Questions**

1. Can head mounted displays and augmented reality increase the efficiency and satisfaction of users in a maintenance context?

2. What possibilities and limitations does the usage of current off-the-shelf head mounted displays lead to?

1.3 **Delimitations**

This thesis project presents techniques that can increase the efficiency and satisfaction of mechanics at a vehicle workshop. Some of the presented functionality will be evaluated by implementing it in a prototype. More precisely, the prototype will focus on aiding mechanics conducting maintenance work on a specific system, the SCR system (see section 2.2) by adopting functionality from existing maintenance programs to work with HMDs and enhancing it with AR.

While this thesis aims to evaluate HMDs in general and how they can support workshop scenarios, the prototype will only be implemented for Google Glass. Wearable devices in general, and HMDs in particular, are expensive devices and it is believed that by implementing a proof of concept application on one device, the introduction of HMDs into a maintenance environment can be explored. Also, most of the current state of the art HMDs share many attributes such as operating system, sensors, connection standards and interaction techniques which makes prototype testing on more than one device unnecessary at this point.
2 Background

This section describes the already existing software and hardware systems that were used together with the developed prototype application. This chapter also gives a brief presentation of the Selective Catalytic Reduction (SCR) system. The prototype implemented during this thesis project will aim at aiding mechanics conducting maintenance work on the (SCR) system. By only focusing on one system, the scope of the prototype is limited so that focus can be put on how the prototype should interact with the existing systems and how the users should interact with the prototype.

2.1 Existing Scania Systems

2.1.1 Vehicle Communication Interface

The Vehicle Communication Interface (VCI) is an interface which lets programs connect to vehicles. The VCI is connected to the CAN bus on the vehicle and can read data from all ECUs. Currently, there are two versions of VCI that are in use, VCI2 and VCI3. VCI2 requires a wired connection between the computer and a vehicle. The new generation, VCI3, offers wireless communication between the vehicle and the computer. Scania has decided that all communication with VCIs should be handled by Scania Communication Module presented below. A VCI3 is depicted in Figure 2.1.
2. BACKGROUND

Figure 2.1: Vehicle Communication Interface 3
2.1. Existing Scania Systems

2.1.2 Scania Communication Module

Scania Communication Module (SCOMM) is a communication component that is used whenever a PC program wants to communicate with an Electronic Control Unit (ECU) on a vehicle. All authorized communication with vehicles has to be handled by SCOMM to fulfil Scania’s requirements. SCOMM includes functionality such as: connect to ECUs; read and delete error messages; read parameters; and read signals. In order to use SCOMM the user needs to be verified either with a hardware key or a software key. The keys are also connected to different permissions that specify what operations the user is allowed to perform on the vehicle. SMAPi is a .Net wrapper included in SCOMM that enables .Net programs to communicate with SCOMM, all new development using SCOMM is recommended to use SMAPi. Scania has multiple systems that communicate with SCOMM through SMAPi, for example Scania Diagnos & Programmer 3 (SDP3) which is used at Scania workshops. The SCOMM architecture is shown in Figure 2.2.

Figure 2.2: SCOMM Architecture
2. Background

2.1.3 Scania Diagnos & Programmer 3

Scania Diagnos & Programmer 3 (SDP3) is a computer based debugging tool developed to make repair and maintenance tasks more efficient. The mechanic can perform diagnostic operations using a laptop, either locally by plugging a cable into the vehicle or remotely by using VCI3 (see section 2.1.1). SDP3 is a .Net program with a graphical interface. It communicates with the CAN bus on the vehicle via the SMAPi interface to gather vehicle data. SDP3 includes functionality such as: read error codes (DTCs), signals and parameters; update Scania Onboard Product Specification if a vehicle is modified; tests and troubleshooting of error codes; adjust parameters; and calibration of components.

![SDP3 Figure](image)

Figure 2.3: SDP3

2.2 Selective Catalytic Reduction (SCR) System

The Selective Catalytic Reduction (SCR) system is an aftertreatment system that controls the chemical process of converting nitrogen oxides, NOx into diatomic nitrogen, N2 and water H2O. By lowering the amount of NOx in the exhaust gas, the emission standards set on vehicles can be met. It is common to use the organic compound urea as the reductant in the chemical process. A schematic view of the SCR system is shown in Figure 2.4. Due to the chemical properties of urea, the liquid tends to transform into solid form which can cause the tubes
in the SCR system to clog up. Because of this, DTC:s are often sent from the SCR system and requires the driver to contact a workshop to fix the errors. Faults in the SCR systems are considered to be of rather high priority since the emission laws require the vehicle manufacturer to apply restrictions such as lowered effect if the NOx levels gets too high.

![Figure 2.4: Schematic view of the SCR system](image)

Since the SCR system is rather error prone and the consequences of a faulty SCR system are severe, Scania has put in a lot of work into trying to make the maintenance of this system easier. In SDP3 the guides for troubleshooting the SCR system have been improved with detailed step-by-step instructions together with a large set of pictures showing how to find the fault. Even though the mechanics had access to the guides in SDP3, Scania engineers noted that the mechanics still had problems solving SCR related issues. Because of this, the engineers designed a SCR test rig, which is described in the next subsection.

Due to the fact that the SCR system is error prone it was decided that the prototype implemented during this thesis project should aim at aiding mechanics conducting maintenance work on the SCR system. This limits the scope of the prototype so that focus can be put on how the prototype should interact with the existing systems and how the users should interact with the prototype. Findings from the implementation of the prototype can then be used as a basis when designing a real product that is used for a broader set of use cases.

### 2.2.1 SCR Test Rig

The SCR test rig, shown in Figure 2.5, is used as a training platform for the SCR system. The goal is to educate the mechanics in how the SCR
2. BACKGROUND

system works as well as provide a better understanding of the components in the system. The test rig only concerns the part of the system that controls the urea fluid levels and does not cover the components connected to heat treatment in the catalytic silencer, nor the engine related parts.

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Figure 2.5: The SCR test rig

Via the valve block housing on the test rig malfunctions can be triggered by turning valves to simulate stops in the tubes. Error codes can then be read from the system by connecting a PC to the test rig and starting SDP3 in the same way as on a real vehicle. The SCR test rig will be used in the evaluation of the implemented prototype by observing how test persons solve SCR issues using the prototype compared to test persons not using it. This will provide a good insight in how the prototype is used in a context similar to the real context at a workshop.
2.2.2 SCR Troubleshooting Guide

To make troubleshooting of the SCR system easier an SDP3 guide has been created that aids the mechanic during pinpointing problems in the system. The guide consists of step-by-step descriptions combined with pictures. To be able to locate the problem the user is asked to detach hoses from the reductant pump and reductant doser as well as measuring how much reductant that comes out of the system. Figure 2.6 shows how a step in the guide looks like.

Figure 2.6: A step in the SDP3 guide
3 Theory

This section presents the theoretical background of this thesis project. It presents previous studies on wearable devices and augmented reality as well as the research methods used during the project.

3.1 Software Quality

In order to evaluate the quality of the prototype clear definitions of what quality means in this project need to be established. Within software engineering, software quality refers to how a software product conforms to some specified set of requirements. Software Quality has been a central part of software engineering for a long time and as the software engineering field has developed, so has the software quality models which have resulted in a scattered set of models [6], [7]. Because of this, a more detailed look on how software quality is defined within this project are given below.

3.1.1 Security

Security is a measurement of how well a software or a platform fulfils its defined security goals [8]. In order to evaluate how secure a system is, a solid definition of the system requirements is needed. According to Matt Bishop [8] security has three components: requirements, which states what to achieve to meet the desired security; policy, which define the
meaning of the security; and security mechanisms, which states which tools and procedures that enforces that step one and two are followed. Although security indicates different things in systems, it is associated with four principles: confidentiality, only authorized subject has access to data or services; authenticity, guarantee that the indicated author or sender is the one responsible for the information; integrity, data should not be corrupted; and availability, data or services should be available in a timely manner [9].

3.1.2 Performance

Performance in the context of computers generally relates to response time (time to complete a request), throughput (how many requests can be processed per time unit) or timeliness (meet deadlines) [9]. In a distributed system it can be difficult to prove that performance requirements are fulfilled, clients and servers are often located on different platforms and communicate over the network. This means that performance might change depending on the distance between the client and server, how high load it currently is on the network etc.

Another possible bottleneck is HMDs. Even though HMDs have decent computational power, heavy operations could slow down the system.

3.1.3 Usability

Usability is the ease of use and acceptability of a system [10]. Ease of use affects the user’s performance and their satisfaction while acceptability affects whether or not the users will use the product. Usability is often broken down into five characteristics: learnability, is the system easy to use for new users; efficiency, will the system help the user to be more productive; memorability, can casual users return to the system after some time without being required to relearn how the system works; low error rate, does the system reduce the chance for error; and satisfaction, is the system pleasant to use [10]. Techniques to evaluate usability can be divided into two main categories, with or without end users [10]. The most common technique that does not involve end users is heuristic evaluation. Experts on usability tests the system and can give feedback. But techniques that involve the end user is often considered the most important. Evaluations with end users can include “think aloud”, field observation and questionnaires.
3.2  Augmented Reality

Augmented Reality (AR) is a technique that combines the real world with a virtual world. It is important to distinguish between Augmented Reality and Virtual Reality (VR) - AR seeks to enhance the real world by imposing virtual objects into it while VR seeks to replace the real world entirely [11]. VR is often used to give a thrilling experience to the user by showing a video or play a video game. AR can be used both as an entertainment tool as well as a professional support tool during work tasks. Since this thesis focuses on usage of HMDs as a support tool, VR will not be discussed further.

The fundamental aim of AR is to improve the vision and hearing of the user and it is therefore an ideal technique to be used as a tool when conducting complex maintenance work. Moreover, previous studies show that AR used together with a HMD can provide great support during maintenance work [1], [2], [3], [4]. These studies showed that AR reduced the time to locate the problem or faulty component as well as limiting head movements since the user could focus on the faulty component instead of reading a manual throughout the task. It was also shown that even if the tested HMDs had shortcomings, the maintenance personnel could accept this if they still gave value to the tasks. Using AR also means that less knowledge needs to be memorized since that information knowledge can instead be stored in the HMD and superimposed, at the right time, into the real world using AR techniques [5].

The following subsections provide a deeper look on the technology that makes AR possible as well as what limitations AR currently has.

3.2.1  Augmented Reality Technologies

To be able to enable AR, some important technologies are required, these are presented below.

3.2.1.1 Displays

While AR can be applied to all human senses, visual is the most common technique [5]. For visual AR, virtual objects (such as pictures or 3D-models) are superimposed into the real world [12]. Visual AR is often implemented with the help of HMDs but is not limited to it [5]. Visual AR is harder to achieve than VR since this requires the user to see the real world combined with virtual objects. Visual AR can be divided into three main categories, video see-trough, optical see-trough and projective [5]. Projective is outside the scope of this report but basically means projecting objects into the real world.
3. **Theory**

Video see-trough is the easiest and cheapest to implement, the real world is recorded and virtual objects are added to the recording and then played for the user. However, video see-trough has some distinct drawbacks, some examples are low resolution and disorientation due to offset between the camera and the eyes of the user [5].

In optical see-trough the users sees the real world while virtual objects are added, either on a see-trough lens or as a projection onto the iris. This means that optical see-trough does not have the same drawbacks as video see-trough. It also has the benefit of not hindering the vision of the user if the device stops working [5]. van Krevelen and Poelman [5] also discusses aural displays that include mono, stereo and surround sound from headphones or speakers.

### 3.2.1.2 Display Position

Apart from the different display techniques for AR, displays can also be classified into different categories based on how they are placed relative to the user. It is common to classify a display technique into one of the three following groups: head mounted, hand-held and spatial [5], [13].

A Head mounted display (HMD) enables the user to place the display on his head providing a display in front of the eyes. HMDs can either use optical see-through, video see-through or a virtual retinal display. Currently, HMDs suffer from having insufficient battery time and too low processing power compared to other portable devices such as smartphones and tablets. Also, the ideal case would be to have HMDs that would be the same size as a pair of sunglasses. HMDs are discussed in detail in section 3.4.

Hand-held devices provide large possibilities to utilize AR due to higher processing power compared to HMDs and low production costs (like mobile phones and tablets) [5]. A drawback compared to HMDs is the fact that the user is required to hold the device in his hand limiting his possibility to interact with the environment.

Spatial techniques include all displays that are placed statically within the environment where AR is intended to take place. The displays can be video see-through, optical see-through or projective displays [5]. These techniques are highly suitable for situations where there is a large audience that experiences AR together. Head-up displays (HUDs) used in airplanes is an example of a spatial display technique.

### 3.2.1.3 Tracking

To be able to display virtual objects into the environment, the AR system must be able to track the user’s movement, this is done by registering position (x, y, z) and orientation (yaw, pitch, roll) [5]. Even though modern
3.2. Augmented Reality

AR devices are equipped with several sensors, tracking is still a complex problem. Optical tracking techniques has shown to be a promising technique for pose estimation, where the camera is used to detect the geometry of the scene by matching established templates[5]. Optical tracking can also be achieved by marker-based tracking, where fiducial markers are placed in the real world to aid optical tracking[13]. Tracking can also rely on environmental 3D models such as a 3D cloud of sample points rendered from a real object or a digital 3D model. The point cloud can then be matched in real-time with the data information fetched from the camera [5]. Tracking can also be achieved by using different sensors such as accelerometers and gyroscopes that can track the movement of the user. Such sensors are often part of a hybrid tracking system where they are used together with other techniques such as optical tracking. A hybrid tracking system has shown to be the best practice for tracking in AR systems [5], [13]. State of the art HMDs have hardware support for optical tracking and also support a wide collection of sensors, making them ideal for using the hybrid tracking technique.

3.2.2 Augmented Reality Limitations

3.2.2.1 Interaction Techniques

An AR system needs to support some kind of interaction with the user. Traditional desktop UIs are not suitable for an AR system since interaction is required in a 3D space as opposed to a 2D space. Moreover, AR devices are seldom equipped with keyboard and mouse. Some research has aimed to replace the mouse with paddles, wands or gloves that are connected to the AR system. Input can also be made with physical icons equipped with markers so the AR system can interpret the input [13]. Instead of hand-worn trackers, gestures can instead be used and tracked by the AR system freeing the user from being required to have objects in his hands. A common interaction technique that has proven to be usable for AR systems is speech recognition. It has been showed to work well as long as the background noise level is not too high [5].

To improve interaction with AR systems, context awareness can be utilized. Since the AR system can track the position and orientation of the user, it can present only suitable information for the current context. This technique limits the complexity of the UI and thus, making it easier to navigate [5].

3.2.2.2 Visualization

When imposing virtual objects into the real world it is vital to be able to render the objects as realistic as possible – the goal is to make the vir-
tual objects indistinguishable from the real ones. To be able to achieve sufficient rendering, the following issues must be addressed: estimating where to render the object with a sufficiently high precision, so real objects that should be visible are not blocked; fading out regions of the rendered object that should be occluded by real objects, so that the depth of the scene is maintained; hiding real objects in the scene that should be occluded by virtual objects; matching the illumination and reflectance of the scene, so that photorealistic rendering is achieved. [5], [13]

3.2.2.3 Human Factors

Even though AR-devices are becoming smaller in size, there are still social issues around them. Devices such as gloves, HMDs and wrist-worn displays are still considered to be too obtrusive for many consumers [5]. There are also discussions on the privacy concerns that arises when cameras can be integrated, almost invisibly, into glasses and watches [5]. Another issue is the fact that wearing a display in front of the eyes for a long period of time can cause both eyestrain and fatigue [13].

3.3 Media Streaming

The effects of different media types when collaborating or receiving remote assistance has interested companies for quite some time. The introduction of AR techniques has made this field even more competitive giving companies a chance to get an edge on the competition [3]. Research so far have not shown any increase in efficiency for white-collar workers but has shown more promises for blue-collar workers [14].

Video, compared to audio, changes how workers and experts communicate. While using video the worker and expert get a shared visual workspace eliminating the need for the worker to explain everything he/she is doing. The expert can see what the worker is doing and comment if he sees something being executed the wrong way and continue with new instructions when he sees that the worker is about to complete the current step. All of this reduces the need for long interactions and is probably the reason that some researchers have seen an increase in efficiency. One could also argue that mistakes could be avoided where the worker thinks he is doing the right thing and reporting back to the expert that continues to the next step even though the worker has not performed the previous step correctly.

Having the camera mounted on the worker’s head [3], [14] has shown to be the best option. This lets the expert see what the worker is looking at and the worker does not have to move the camera and can always use both hands to perform the labour, making HMDs perfect for remote support. S. Bottecchia et al. [3] state the importance of the quality of
3.4 Wearable Devices

the video sent to the expert, with low video quality the experts have difficulties to identify components. Minimizing delays is also of great importance for changing the way workers and experts interact. If the stream has a high delay, input from the expert will sometimes arrive after the worker performed a certain task. This can result in failed communication and the video stream can be a liability instead of a helpful tool. The problem with these two parameters is that they do not work well together, higher quality often lead to higher latency and vice versa.

Streaming video between the expert and the worker also enables the possibility for the expert to add virtual objects on the workers screen which could increase the efficiency even more.

3.4 Wearable Devices

A wearable device can be anything from a digital smart watch to a large backpack containing a modified laptop computer or clothing with printed electronics. Due to this vast array of device types there is a large set of contexts where these devices could be used and different device types are suitable for different contexts. For example, within a maintenance context where the user wants to receive information without using his hands, a suitable device can be a HMD or a wrist worn smart watch.

A field that lies rather close to wearable devices is augmented reality (AR) and a great amount of surveys on wearable devices and AR has been carried out during the last 20 years. The earlier surveys presented many interesting cases where AR and wearable devices could be used to aid employees in different contexts [12], [13], [15]. The motivation for this was that AR could be used to show information that the user could not access on his own. The early idea was that instructions or information would be easier to comprehend if it was shown “in” the real world and not as pictures or text on paper. If the instructions could also be animated, it would be even easier to understand [12]. From these thoughts, the interest for usage of wearable devices and AR to support operators during maintenance and repair of machines increased and more studies were carried out. Prototypes created from these studies verified that AR could indeed increase performance and reduce errors during maintenance operations [3], [4].

As the complexity of mechanical and electronic systems grew, the demand for new technical assistance tools increased. Mechanics and other field personnel could no longer possess all the detailed knowledge to solve every possible problem on their own. Wearable technology has proved itself useful in these scenarios due to its interaction transparency—mechanics could interact with a remote expert and still be able to use their hands [3], [16]. By also sharing audio and the visual space, using
3. Theory

A device that was equipped with a camera and microphone, better collaboration was achieved that led to shorter time to accomplish tasks and with less errors [1], [14], [17]. When the expert was able to see what the mechanic saw, the expert could put markers that were augmented in the mechanics view.

Although there is a clear benefit from using wearable devices and AR, as shown by previous research, limitations also exist. Prototypes that used augmented markers to identify objects suffered from insufficient accuracy from the tracking device [16], causing the augmentation to be badly rendered or not rendered at all. Another example is that the required components that make AR possible (trackers, displays, batteries) had too bad accuracy, were not portable enough, were too expensive or had too short battery life [13].

3.4.1 Head Mounted Displays

The client application will be implemented on Google Glass. However, this thesis aims to evaluate how AR and HMDs in general can improve maintenance and other vehicle services and should not be restricted to Google Glass. In Table 3.1 a list of some state of the art HMDs and their specifications are presented.
### Wearable Devices

#### Table 3.1: HMD Comparison

<table>
<thead>
<tr>
<th>Model/Feature</th>
<th>Google Glass</th>
<th>Moverio BT-200</th>
<th>Vuzix M100</th>
<th>Optinvent ORA-S</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Image resolution</strong></td>
<td>640x360</td>
<td>960x540</td>
<td>240x400</td>
<td>640x480</td>
</tr>
<tr>
<td><strong>Image location</strong></td>
<td>Upper right corner</td>
<td>Centred</td>
<td>Unknown</td>
<td>Centred or bottom</td>
</tr>
<tr>
<td><strong>See through</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Number of displays</strong></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Camera</strong></td>
<td>5mp/720p</td>
<td>VGA (640x480)</td>
<td>5mp/1080p</td>
<td>5mp/1080p</td>
</tr>
<tr>
<td><strong>Processor</strong></td>
<td>1.2Ghz dual core</td>
<td>1.2Ghz dual core</td>
<td>1.2Ghz dual core</td>
<td>1.2Ghz dual core</td>
</tr>
<tr>
<td><strong>RAM</strong></td>
<td>2 GB</td>
<td>1 GB</td>
<td>1 GB</td>
<td>1 GB</td>
</tr>
<tr>
<td><strong>Memory</strong></td>
<td>12 GB</td>
<td>8 GB internal, 32 GB MicroSD</td>
<td>4 GB internal, 32 GB MicroSD</td>
<td>4 GB</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>50g</td>
<td>88g + 124g controller</td>
<td>Unknown</td>
<td>80g</td>
</tr>
<tr>
<td><strong>Requires extra device</strong></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Operation system</strong></td>
<td>Android</td>
<td>Android</td>
<td>Android</td>
<td>Android</td>
</tr>
<tr>
<td><strong>Connections</strong></td>
<td>Wi-Fi and Bluetooth</td>
<td>Wi-Fi and Bluetooth</td>
<td>Wi-Fi and Bluetooth</td>
<td>Wi-Fi and Bluetooth</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
<td>Touchpad and voice commands</td>
<td>Touchpad and buttons</td>
<td>Four control buttons, remote control app, voice commands and gestures</td>
<td>Touchpad and voice commands.</td>
</tr>
<tr>
<td><strong>Gyroscope</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

19
As HMDs are a relatively new technique, at least on the commercial market, it does not have any standardized specifications which makes comparing units hard. However, state of the art HMDs have quite similar specifications. All of them run on some version of the Android operation system, they all have a dual core processor with the same frequency and one to two GB of RAM. All models have support for both Wi-Fi and Bluetooth connection.

Screen resolution on the other hand can differ a lot between different models. Moverio BT-200 has the highest resolution at 960x540px while Vuzix M100 has the lowest at 240x400px. Vuzix M100 is the only one that uses video see-through while the others have optical see-trough. The image location specifies where the screen is located relative to the user’s normal field of view. The screen on Google glass is located in the upper right corner, on Moverio BT-200 it is centred and the only device that has displays for both eyes. Optinvent ORA-S, has a screen that can be moved between two locations offering the flexibility to choose between centred and bottom. No data was found indicating where the screen on Vuzix M100 is located. In order to support true AR functionality a centered screen is needed since the HMD must cover the major part of the user’s field of view.

All models support interaction with either a touchscreen or buttons and all models are equipped with a gyroscope. All models except Moverio BT-200 can also be navigated with voice commands. Vuzix M100 is the only one with support for gesture commands. Moverio BT-200 needs to be connected to a controller to run, this explaining the much higher weight on this device. All HMDs in Table 3.1 can be connected to other devices through Bluetooth to enable more complex interactions.

Battery life is another property that is interesting. However, sufficient information about this aspect could not be found for all models and was therefore left out.

### 3.4.2 Authentication

Using a wearable device to connect to a vehicle or another complex system also puts requirements on security. Without some sort of authentication, anyone could connect to a vehicle and corrupt its data. To solve this, the system has to require users to authenticate themselves so only authorized users have access to the platform. For PCs and other devices that have keyboards, password-based authentication is the most common way [18]. Each user has a username and a password that they need to provide to be able to sign in to a service. The username and password is checked against a database and if it matches the user is au-
3.4. Wearable Devices

authorized and gain access to the service. All HMDs currently on the market lack the support for an easy way to enter text. However, there are some workarounds:

- **Using the gyroscope.** Some prototypes have started to surface taking use of the gyroscope and touchpads to enable relatively quick text input. The gyroscope could for example be used to move a marker over a keyboard and have a physical button that is used to select a character.

- **Using speech recognition.** Speech recognition is another way to enter usernames and passwords. But this raises problems as described by D. Bailey et al. [19]. When entering the password an attacker can easily overhear the password. D. Bailey et al. [19] give some proposals for how the security for inputting passwords via speech recognition can be improved. One example is to map each character to a randomized character and showing the randomized character together with the real character on the screen, then letting the user speak the corresponding randomized character instead of the real one.

- **Using a second device.** By using a second device that has better support for text input. The user could login on a computer or a cell. After the user has logged in on another device the HMD needs to receive the information from the second device. This could be done in multiple ways. One example is to connect the HMD and the second device via a Bluetooth or Wi-Fi connection and send over the secret access token to the HMD. Another way is to serialize the token into a QR-code or similar on the second device and then scan the QR-code from the HMD, the upside with this alternative is that it does not require the second device to have Bluetooth or any other pre-established connection between the HMD and the device.

- **Using biometric techniques.** While none of the HMDs looked at in this thesis have any support for biometrics, if added in the future it could solve a lot of the problems occurring when trying to authenticate a user from a HMD. It can remove the need for any text input at all. Possible biometrics that could be used are fingerprints, face-recognition, iris- and voice recognition. Unfortunately, biometrics introduce new problems. Extra hardware is often required and that can increase the weight and cost of the device [19]. Biometrics are also the only authentication method that is not exact, meaning that a biometric system needs to allow users into the system based on how close they are to a match with an authorized user. If this threshold is low then the system might have
many false-positive meaning that users that should not have access to the system would be authorized anyway. On the other hand, with a high threshold the system might have many false-negatives meaning that users that should be authorized are not.

3.5 Research Methodologies

There are several research methodologies that can be used to get a better understanding of new domains and identify problems that could be solved by a new system. By using already established research methodologies or models, the risk of missing important tasks during the research are limited and thus, reliability is increased. A suitable model for research on information systems is the design science model, described below.

3.5.1 Design Science

The design science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artefacts [20]. In other words, design science aims to create and evaluate IT products that solve or help with identified problems where no best practice exists. This corresponds well to the purpose of this project which makes design science the ideal choice.

K. Peffers, et al. [21] presents a model extracted from previous research in the area in an attempt to design a methodology that could work as a framework for carrying out design science research. It contains six activities, depending on how far the artefact is from a finished product step four and five might be skipped. A visual presentation of this model is presented in Figure 3.1.

1. **Problem identification and motivation.** Define the problem and justify the value of a solution. In order to perform this activity the researchers need to understand the problem and why a solution is needed. Information is often gathered in form of case studies or field studies.

2. **Define the objectives for a solution.** When has an artefact improved or solved a problem? This can be specified both quantitatively and qualitatively, for example in maximum time to complete a task. In order to complete this activity knowledge about the problem and current solutions, if any exists, is needed.

3. **Design and development.** In this activity the artefact’s functionality and architecture should be specified. After it is determined what the artefact should do and how, it should be implemented.
4. **Demonstration.** Demonstrate the use of the artefact, this can be done by experiment, case studies or some other technique. Demonstration is usually performed if the artefact is in an early prototype stage.

5. **Evaluation.** Observe and measure how much the artefact contribute to reaching the goals set up in activity two. The artefact could also be compared to the old solution to the problem. One test group could use the old system while another group use the new artefact. The results from the two groups can then be compared and evaluated.

6. **Communication.** Communicate the problem and the importance of solving it, does it contribute to the field, can the artefact help the company increase its effectiveness, save money or increase the company’s reputation?

![Figure 3.1: Design Science Model](image)

A R. Hevner, et al. [20] argue that when conducting design science on information systems it is equally important to consider behavioral science. This becomes clear when looking at some of the activities, such as the first activity where case studies often are conducted.

### 3.5.2 Research Methodology Characteristics

Research methodologies can be classified in several ways, however the most common classification are quantitative and qualitative research methods. Quantitative research includes numbers and numerical methods applied on those numbers while qualitative research focuses on words and descriptions.
Robson [22] defines four types of purposes for research, namely: Exploratory which aims to provide an understanding of what is happening and to aid in creating new research hypotheses; Descriptive that is used to describe or portray a situation within a real-life context; Explanatory that seeks to explain a situation; and Improving that is used to improve a real-life situation. P. Runeson and M. Höst [23] use previous papers on research methodologies to present four research methodologies that are commonly used when conducting studies. These are: Case study, an empirical method used to observe or investigate a phenomena in their real-life context; Survey, that uses interviews or questionnaires to collect information from a set of subjects; Experiment, that measures how one variable is affected when another variable is being manipulated; and Action research, that closely resembles a case study except that a case study is purely used for observation while action research aims to influence some aspect of the phenomena.

From Robson’s [22] purpose definitions and the presented methodologies summarized from previous papers, P. Runeson and M. Höst [23] provide an overview of the research methodologies and for what purpose they should be used. The overview is presented in Table 3.2.

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Objective</th>
<th>Classification</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case Study</td>
<td>Exploratory</td>
<td>Qualitative</td>
<td>Flexible</td>
</tr>
<tr>
<td>Survey</td>
<td>Descriptive</td>
<td>Quantitative</td>
<td>Fixed</td>
</tr>
<tr>
<td>Experiment</td>
<td>Explanatory</td>
<td>Quantitative</td>
<td>Fixed</td>
</tr>
<tr>
<td>Action Research</td>
<td>Improving</td>
<td>Qualitative</td>
<td>Flexible</td>
</tr>
</tbody>
</table>

Table 3.2: Research Methodology Characteristics

While case studies can be based on both quantitative and qualitative data the most common is qualitative as this kind of data supports richer and deeper descriptions from the subjects. Case studies are ideal to provide a deeper understanding of the phenomena under study and to generate new research hypotheses, hence the Exploratory characteristic [23]. Also, case studies have a flexible design since a fixed design means that all parameters are defined at the start of the study which would constrain the exploratory nature of the case study. The case study research method is presented in detail in section 3.6 below.
3.6 Case Study

According to P. Runeson and M. Höst [23], good planning is crucial for a successful case study. Before carrying out a case study, there are several issues that the researchers have to plan for and summarize in a planning document. The objective of the study and the questions that should be answered have to be defined. The methods used for data collection have to be selected as well as which subjects (departments, persons etc.) that should be studied. The sections below describe some activities and key points when conducting case studies [23].

3.6.1 Data Sources

Possible data sources for qualitative case studies include observations, interviews, participant observations, questionnaires, documents and text [24]. Interviews and observations are described in the sections below.

3.6.1.1 Interviews

By asking the subject questions about the area data is collected. The questions can be open letting the subject reflect over possible answers or closed e.g. yes or no questions. Interviews can be categorized as structured, semi-structured or unstructured [22]. During structured interviews all questions are established beforehand and the interviewer should not deviate from the questions in any way. In semi-structured interviews a list of questions is prepared beforehand but the researchers are allowed to decide the order of the questions and have the freedom to improvise and ask questions as they see fit. Unstructured interviews gives the interviewers freedom to ask any question they see fit. Unstructured interviews are often used when the research is of the exploratory nature.

3.6.1.2 Observations

To identify problems that the subjects themselves are not thinking about observation techniques can be used. Observations also help the researchers to get a deeper understanding of the context studied. Observations studies can be classified depending on the awareness of the subject being observed [23]. The subjects are often told to use the “think aloud” technique, which mean telling the researchers what they think while performing their tasks. The “think aloud” method is often used in observation studies where the subjects have a high awareness of being observed.
3.6.2 Data Analysis

In an exploratory research method such as a case study, it is important to use flexible analysis methods that work even though the gathering techniques change. More precisely, quantitative analysis cannot be used if a research question is changed during the gathering phase since this will cause erroneous statistical values [23]. Another aspect that contradicts usage of quantitative analysis in case studies is the fact that data sets often tend to be small, and therefore not suitable for statistical models [23].

The main purpose of data analysis is to extract valuable conclusions from the collected data. Such conclusions can either be new hypotheses or a confirmation of already established hypotheses. When analyzing, it is vital to keep a clear chain of evidence, this means that a reader should be able to understand how the conclusion was derived and other researchers should be able to repeat the study to verify the result [25]. In qualitative research it can be hard to keep a clear chain of evidence since the methods are often flexible and assumptions and observations can be used to alter the research questions or approaches during the study. This means that a solid method for analyzing the qualitative data is needed, one example of such a method is the tabulation method presented by P. Runeson and M. Höst [23]. When using the tabulation method, the gathered data is grouped into so called themes where each theme answers a specific area even though the individual answers can differ to some extent.

3.6.3 Validity and Reliability

Validity and reliability are two factors often discussed when conducting case studies and some doubts are raised against case studies in this area. Threats to validity and reliability in case studies can be divided into the following four types [26]:

- **Observer-caused effects**, there is a risk that the subjects change their behaviour and perform tasks differently compared to when they are not being observed.

- **Observer bias**, case studies require the researchers to have prior knowledge about the situation being observed [27], this means that the researchers might already have an idea about how to solve the problem or how people work in the given situation which can make the researcher more alert to information contributing to their idea.

- **Data access limitations**, case studies are conducted during a limited period of time and that time period might not reflect the normal
state of the situation. In many cases the researchers have to choose a typical site for the observations and failing to do so can produce faulty information.

- **Complexities and limitations of the human mind**, the subject might mislead the researchers unintentionally or on purpose. The subject might report scenarios in a way that is flattering or acceptable to himself.

Validity and reliability can be classified into four categories: 

- Construct validity that reflects whether the case study is constructed in a way that subjects and other researchers reading the report are interpreting the case study in the same way as the researchers conducting the research;
- Internal validity that describes to what extent the studied phenomena is affected by other factors that the researchers are unaware of;
- External validity that is concerned with how well the information from the study can be used by other people outside this case;
- Reliability that reflects to what extent the study can be replicated by others and to what degree the data and analysis is dependent on the assumptions of the researchers.

### 3.7 System Usability Scale

In order to evaluate how good the prototype is in a usability perspective the System Usability Scale (SUS) can be used. SUS was developed by J. Brooke and is often used when evaluating usability on software systems. SUS evaluates the usability parameters effectiveness, efficiency and satisfaction and consists of the following 10 questions:

1. I think that I would like to use this system frequently
2. I found the system unnecessarily complex
3. I thought the system was easy to use
4. I think that I would need the support of a technical person to be able to use this system
5. I found the various functions in this system were well integrated
6. I thought there was too much inconsistency in this system
7. I would imagine that most people would learn to use this system very quickly
8. I found the system very cumbersome to use
9. I felt very confident using the system
3. Theory

10. I needed to learn a lot of things before I could get going with this system

Each question is answered with a value between one to five. One means strongly disagree and five strongly agree. From these values a SUS-score is calculated. To calculate the score for question 1, 3, 5, 7 and 9, the answered values are subtracted with 1. To calculate the score for question 2, 4, 6, 8 and 10, the answered values are subtracted from 5. All scores are then summed up and multiplied by 2.5. This results in a value between 0 and 100. Jeff Sauro [29] have compiled over 500 SUS-evaluations, the results are shown in Figure 3.2. Getting a score over 80.3 puts the system in the top 10% which is considered as excellent.

![Figure 3.2: Result from Sauro’s SUS-evaluation](image)

Figure 3.2: Result from Sauro’s SUS-evaluation
This section describes the applied methodologies and is structured according to the different phases carried out during the project. First design science and how it relates to the phases carried out is described. Section 4.2 describes the qualitative research method used during the prestudy phase. Section 4.3 gives an overview of how the implementation phase was carried out to support the development of the prototype. Finally, section 4.4 summarizes how the evaluation phase was carried out.

4.1 Design Science

The design science process spans over the whole project. Design science does not describe exactly how any of the steps should be performed but gives a good baseline for what activities this type of project should involve. The following list describes how phases in this project correspond to activities in the design science model presented by K. Peffers, et al. [21].

1. **Problem identification and motivation.** This activity corresponds to the case study that was performed at the workshop. See section 4.2 for more information.

2. **Define the objectives for a solution.** The objective was directly derived from the research question: “Can head mounted displays
4. **Method**

and augmented reality increase the efficiency and satisfaction of users in a maintenance context?”. Thus, the objective is to increase usability within the maintenance context.

3. **Design and development.** This activity corresponds to the implementation of the prototype. See section 4.3 for more information.

4. **Evaluation.** Activity four corresponds to the evaluation phase of the project where the prototype was compared to the existing program SDP3. Findings from this comparison were then summarized and analyzed. See section 4.4 for more information.

5. **Communication.** This activity is covered by publishing this report. The findings from this project are communicated through this report and therefore communicated to others.

4.2 **Prestudy**

The purpose of the prestudy was to provide an insight into the processes of the vehicle workshops and to study possible problems that could be solved with wearable technology and improvements compared to the old systems. The prestudy phase was carried out as a case study with the research questions used as initial case study questions. From the research questions, hypotheses on how wearable devices and AR techniques could be used to improve processes at the vehicle workshop were established. The hypotheses were then used in the implementation phase as the initial guidance for how the prototype should be implemented.

The remainder of this section motivates the choice of research method during the prestudy. The research method is then described in detail and concluded together with a discussion on validity and reliability.

4.2.1 **Research Method**

Case study was chosen as the most reasonable method for the prestudy phase. The case study was conducted in an exploratory fashion using qualitative data analysis methods. The aim of the prestudy was to provide a deeper understanding of common problems at the vehicle workshop to be able to develop new hypotheses on how wearable devices can aid in solving these problems.

4.2.2 **Objective and Case**

The objective of the case study was to perform exploratory research in a vehicle workshop. The case study was expected to generate hypotheses
on how wearable devices and AR can be used in the vehicle workshop. By conducting the study, a better understanding of what the prototype should focus on was established making it clearer how to proceed with the project.

The choice to take the viewpoint of the mechanics was natural since they are the most probable users that would benefit from using a wearable device in a maintenance context. From this assumption it was clear that maintenance workers in vehicle workshops had to be observed while they were performing routine work. The researchers observed and noted any obstacles that were encountered during the routine work and how these problems were solved as well as what problems that were most frequently occurring and most time consuming. A set of interview questions was also held with the workers to broaden the perspective of the study, see section 4.2.4 for more information.

4.2.3 Research Questions

The research questions for the case study was directly derived from the initial research question “Can head mounted displays and augmented reality increase the efficiency and satisfaction of users in a maintenance context?”. To be able to answer this question, the researchers focused on the most common problems and how the mechanics solved them as well as what tasks that were most time consuming.

4.2.4 Data Sources

To get insight in the obstacles mechanics encounter during a workday the researchers will both observe and conduct interviews with the mechanics.

4.2.4.1 Interviews

In the beginning of the interview more open questions were used to not steer the subject in any direction, if more specific questions were needed they were asked later in the interview. The researchers conducted a semi-structured interview. The exploratory nature of the case study could make one argue for unstructured interviews, but due to the lack of experience conducting interviews among the researchers semi-structured interviews were chosen.

The interviews were conducted in Swedish and the following questions are the prepared interview questions translated into English:

- What do your work assignments include?
4. Method

- How long have you been assigned these tasks?
- How many tasks do you perform per day?
- What are the most common obstacles you encounter during these tasks?
- What part of the tasks are most time consuming?
- Do you have a smartphone? If yes, do you use it as support in your work assignment?
- Do you think HMDs could help you in your daily work? If yes, then how?
- If a problem is too complex to solve by yourself, how do you proceed?
- Do you ever have problem locating components? Is this a common problem?
- If you have to contact an “expert” to solve a task, by your estimate, how long does these contacts usually take? Would it be helpful if the “expert” could see what you see?

4.2.4.2 Observations

To identify what problems mechanics face at the workshop and other issues that the mechanics themselves did not consider during the interviews, the observation technique was used. In this study the subjects were well informed of the observation and they knew the reason for the observational study. The subjects were told to use the “think aloud” technique. During the observations data was collected by taking notes. Notes are useful to summarize the most obvious conclusions and can be used on site without having to analyze a lot of material.

4.2.5 Data Analysis

During the interviews and observations, the researchers took notes that summarized both important observations and answers to the questions asked. To increase the validity of the case study, the researchers took separate notes which was later merged, see section 4.2.6 for more information. After the data gathering, the notes were analyzed and grouped according to the tabulation method presented by P. Runeson and M. Höst [23]. Each answer was grouped based on which theme the answer corresponded to. The grouped data was then summarized in a diagram, which can be seen in Figure 5.1. This summary provided a good overview of
the data that made it easier to draw valuable conclusions from the case study.

4.2.6 Validity and Reliability
In this project several steps are taken to minimize the possible threats when conducting case studies and to best fulfill validity and reliability:

- By interviewing and observing multiple subjects. Basing conclusions on multiple subjects increases the chances of finding problems concerning all employees.

- During the observations and interviews two researchers were present to achieve observer triangulation.

- Two different methods to collect data were used, interviews and observations. Using multiple methods to collect data decreases the risks of interpretation effects from one single data source. Drawing the same conclusion from multiple data sources increases the validity of the conclusion i.e. data source triangulation [23].

4.3 Implementation
This section describes the implementation phase of the thesis project. The implementation phase was divided into client side and server side implementation which was developed incrementally and in parallel. The findings from the case study worked as a guidance to create a list of what functionality the system should offer as well as in what order the functionality should be implemented:

1. Read All ECUs from a selected VCI
2. Read All DTCs from a selected ECU
3. Erase a selected DTC
4. Start a troubleshooting guide from a selected DTC
5. Use Augmented Reality to aid the troubleshooting from within a selected guide

Each step was implemented fully to ensure a working prototype and not a half finished product. All code was reviewed by at least one person to increase code quality. After each step was implemented it was presented and tested by experts at Scania.
4. Method

4.4 Evaluation

After the prototype was finalized, the evaluation phase was initiated. The evaluation phase was performed as a comparison between the existing system, SDP3, and the new Google Glass application. The following subsections describe the evaluation phase in detail.

4.4.1 Objective and Method

The objective of the evaluation phase was to evaluate the usability of the prototype to answer the research question “Can head mounted displays and augmented reality increase the efficiency and satisfaction of users in a maintenance context?”. To be able to assess if usability was increased the usability of both SDP3 and the Google Glass application was measured and then compared. This was done by dividing the subjects into two groups, one group used SDP3 and one used the Google Glass application. Both groups were tasked with the same assignment, to execute the troubleshooting guide for the SCR system to find and correct the faults in the system.

4.4.2 Data Sources

During the evaluation phase both quantitative and qualitative data was collected. The quantitative data consists of error rate and time to completion. This data was measured when the subject was conducting the troubleshooting of the SCR system. All steps had to be performed correctly to get a pass without errors. If a subject got an error, no time will be noted and the task marked as failed. If a subject finished the task without any errors their time was noted.

The qualitative part was based on questionnaires and interviews. Right after the task was finished the subjects was tasked with a SUS-test, this was used to get a well-established method to measure usability. The SUS-test was followed by an interview with more specific questions on the system. The interviews were conducted as semi-structured interviews in the same manner as the interviews held during the prestudy phase, a list of questions were prepared before the interview but the researchers were allowed to ask the question in any order as well as letting the subject speak freely around any question.

Different sets of questions were asked depending on which system the subject used. The following sets of questions were used in the interviews.

Questions to subjects using the Google Glass application:

1. Have you used SDP3 before?
2. Have you executed this guide or task before?
3. Are you working with maintenance work in your profession?
4. What was your overall impression of the guide?
5. Were any specific steps difficult to understand/perform?
6. Was the layout/interface easy to understand?
7. Which of the two rendered objects in the companion app did you prefer?
8. How can the application be improved?
9. What are your thoughts on Google Glass?
10. Have you used Google Glass or another HMD before?
11. If the user has used SDP3: which did you prefer the prototype or SDP3, and why?
12. Anything else you would like to add?

Questions to subjects using the SDP3 application:
1. Have you used SDP3 before?
2. Have you executed this guide or task before?
3. Are you working with maintenance work in your profession?
4. What was your overall impression of the guide?
5. Were any specific steps difficult to understand/perform?
6. Was the layout/interface easy to understand?
7. How can the application be improved?
8. Anything else you would like to add?
4.3 Data Analysis

To compare the quantitative data, the average time to completion for the two systems was calculated. The average time to completion together with the error rate shows how the systems compare in terms of efficiency.

The results from the SUS-test were analyzed by comparing the average SUS-score of the two systems and gives an insight into how the two systems compare in terms of efficiency and satisfaction.

The interview questions were analyzed using the tabulation method [23]. From the interviews, the researchers wrote down the answers from the subjects. These answers were then grouped according to different themes to be able to summarize the answers. The summary can be seen in Figure 5.9 and 5.10.

To increase the amount of information gathered during the evaluation, the researchers also noted any interesting observations that was observed during the tests.

4.4 Validity and Reliability

To increase the validity and reliability of the evaluation phase, the following steps were taken:

- During the evaluation, two researchers were present to achieve observer triangulation and to decrease biased assumptions.

- The evaluation was based on multiple subjects which increases validity.

- Since both quantitative and qualitative data was collected, data triangulation is achieved. This decreases the risk of interpreting the data wrong and therefore increases the validity of the research.

- By using SUS, a well-established method for measuring usability, the validity of the evaluation is increased.
5 Results

5.1 Prestudy

The case study resulted in interview data from five mechanics at the vehicle workshop as well as an unstructured group interview with six other mechanics. As a complement to the interviews, notable observations made by the observers were written down.

All of the interviewed subjects were employed as mechanics on trucks or buses. There was also mix in how long the mechanics had been working with these assignments, from over ten years to a couple of months. Even though there was a difference in how experienced the subjects were, there was a strong correlation in many of the answers to the interview questions.

The majority of the subjects claimed that they were using the existing system, SDP3, as a starting point when carrying out vehicle diagnostics tasks. This finding is important to motivate the implementation of any aiding information system. If the users feel that the already existing system is too cumbersome to use, the reason for this should first be examined to find out what a new system should do differently.
5. Results

5.1.1 Interview Results

Figure 5.1 shows the answers from the interviews after they have been grouped into themes and how many of the mechanics that matched that theme. In the following subsections each theme is discussed in detail.

![Figure 5.1: Interview results]

5.1.1.1 The existing program SDP3 has too large loading times

All subjects claimed that connecting SDP3 to a vehicle takes too long. This is probably due to the fact that SDP3 extracts all required information (error codes, signals and parameters) directly. Loading time and responsiveness is important for how user experiences a program. This could be solved by only reading data when needed, data could also be loaded in the background resulting in an even faster system.

5.1.1.2 The laptop PC is not flexible enough/too fragile

Even though the PC is the standard tool used by the mechanic to perform diagnostics operations on the vehicles a majority of the subjects complained on the fact that the usage of a PC was cumbersome. This is due to the fact that most of the subjects were using VCI2 which means that the PC had to be connected to the vehicle with a cable, limiting the possibility to move around with the PC drastically.

Often, the mechanic had the PC placed on one side of the vehicle while working on the other side. In such cases the mechanic first started the PC program and read the error codes. He then had to move to the area where the component he thought caused the error. After he has repaired or changed the component he had to move back to the PC again and
check if the error code is resolved. Sometimes the mechanic is forced to do this several times before he finds and corrects the root of the error. It is clear that the mechanic can benefit greatly by using a HMD in this scenario. He can then monitor the error codes in the device and directly get notified when the error is resolved.

Of course, using the new VCI3 (using wireless connection) which enables the mechanic to place the PC wherever he wants, solves a part of this problem. However, a great part of tasks is performed in positions when the mechanic cannot operate a computer. This can for example be working under the vehicle or standing by the engine where a PC cannot be placed. For such cases a head mounted display is more suitable since the mechanic can stand under the vehicle and still get information about the status of the vehicle. If the HMD fully supports operation by voice, the mechanic can still use both his hands while monitoring the error codes.

Another important aspect that some subjects claimed was the fact that the PC is too fragile. The subjects claimed that they could not use the PC to its full potential since they had to be careful where they placed it and how they used it. Even though an off-the-shelf HMD device probably isn’t more durable than a computer, it can be used differently than a PC which could possibly mean that it would last longer. For example, a PC has to be placed on a surface which could be hot or covered with substances that can damage electronics, HMD:s are placed on the head in the same way as a normal set of glasses which keeps them away from harmful surfaces.

5.1.1.3 The existing guides in SDP3 are not clear enough

The guides in SDP3 are used to support the mechanic when troubleshooting the vehicle systems. It is worth to mention that a lot of work has been put on some of the guides to make them easier to follow. Most importantly, images have been added to the guides to make them more understandable. Despite this, some subjects pointed out that the guides in SDP3 are still hard to understand and follow. One reason that was mentioned was that the pictures were unclear and did not depict reality sufficiently, another was that there were too few pictures. Figure 2.6 shows how a step in a picture based guide looks.

The guides could be enhanced with augmented reality techniques to make them more understandable. For example, the images could be rendered directly over the object to make it more clear how to perform the step in the guide. This technique would require the glasses to recognize the physical object and map it to an image and then render it correctly on top of the physical object. Another way to enhance the guides would be to render a 3D model of the component that the mechanic should work
with in the peripheral vision. This could increase the understandability since the mechanic could then see the physical object clearly and still compare it to the 3D model. The mechanic could also benefit from this if he is able to rotate the model directly in the HMD, by using the gyroscope for example. The textual information in the guides could also be presented in the HMD to make it even clearer.

Some of the guides contain steps that require the mechanic to perform hazardous tasks such as detaching hoses with high pressure or removing hot components. The information in the glasses could then be enhanced with warnings to prevent injuries.

5.1.1.4 Using audio/video when contacting remote support would be beneficial

The subjects claimed that it is rather uncommon that they have to contact remote support since the required knowledge can often be found at the vehicle workshop directly. However, when contacting remote support, the subject pointed out that it was sometimes hard to explain the problem. Moreover, they emphasized the benefit of a remote expert being able to connect to the vehicle remotely (as offered by VCI3). This made it possible for the expert to read the error codes to get a better understanding of the problem. The subjects also thought that being able to send pictures or sound to remote support would make it easier to explain the problem.

This problem could be improved by using HMD:s as the expert could then receive streamed audio and video of what the mechanic sees in real time. This provides a shared visual space between the participants which can lead to significantly decreased time for solving remote support scenarios. Also, since the mechanic can use both his hands and still communicate and share visual space with the expert, the expert can guide the mechanic through tasks that the mechanic is unfamiliar with.

5.1.1.5 Monitoring signals in real time during tests would be beneficial

Sometimes the mechanic is required to start pre-defined tests from SDP3. The purpose can be to examine a part of a system for errors or validate that a system works as expected. For some of these tests the mechanic is required to monitor the signals on the PC during the test. Since some tests can take several minutes the mechanic could benefit from being able to monitor the signals in a HMD while performing other tasks or examining the physical components at the same time. The HMD can then also warn the mechanic directly if a signal value exceeds a set value, for example if the pressure in a pumping system is too high.
5.1. Prestudy

The same technique can be used when the mechanic performs other tasks. If the HMD knows what system the mechanic works on, for example from what error code the mechanic selected, it can automatically monitor the signals from that system and warn the mechanic if signals exceed secure levels.

5.1.2 Observation Results

As mentioned earlier, the case study captured information from both interviews and observations. The interviews gave valuable insights into how normal work tasks in the vehicle workshop looks like, but they did not depict other parameters that may affect how a new information system should be implemented and used. Such parameters can for example be how the work environment looks like or how the subjects are interacting with already existing information systems. The observations aim to capture such information.

From the observations, three important conclusions could be made. These conclusions are discussed in detail in the subsections below.

5.1.2.1 Location of vehicle components limits the feasibility of object recognition

During observation the observers noted that the subjects often had to reach in, behind other objects, to be able to reach the required component. This means that the component is not always visible from where the mechanic stands and thus, making object recognition infeasible. In such cases it is probably more beneficial to present information on how the mechanic can remove objects to reach the desired component. Such information, presented in the mechanics peripheral view, can for example be textual step-by-step information, exploded-view drawings or 3D animations showing how to perform disassembly.

The observers also noted that tasks requiring subjects to work under the vehicle, may lead to insufficient lightning conditions to support object recognition. Moreover, many components located under the vehicle were often soiled with dirt that could impede recognition further.

5.1.2.2 The noise level at the workshop can hinder sufficient speech recognition in some situations

It was also noted that it was sometimes a high noise level in the workshop when mechanics performed welding or cutting. One of the benefits of using HMD:s is that the user can interact with it by voice and using his hands for other things simultaneously. High noise levels can of course impair the speech recognition functionality and it is therefore important
5. Results

to provide multiple interaction techniques and not only speech recognition.

5.1.2.3 Mechanics are often required to move to the PC to check for new information during tasks.

As pointed out by several subjects, the PC connected by wire required the subjects to return to the PC during some tasks to observe changes in the system. This leads to unnecessary movement and impedes real time monitoring. This problem is solved by using a HMD which can provide a real time overview of interesting signals from the vehicle as already discussed in section 5.1.1.5 above.

5.1.3 Prestudy Conclusions and Decisions

The prestudy results showed several areas that could be improved. Several interviewees stated that the PC was cumbersome to use in the workshops, HMDs could possibly be more user-friendly in this environment. The SDP3 guides where described as unclear and hard to follow, this is due to large amounts of text and pictures that did not depict reality sufficiently. Large amounts of text could possibly be replaced with AR and pictures could be replaced with objects rendered over the physical component. The mechanics could aid from having a HMD that lets them monitor signals while performing other tasks or notifies the mechanic when a signal reaches a specific value.

A prototype was implemented to tests these hypotheses. To evaluate the correctness of these hypotheses, the prototype was compared to SDP3. Section 5.2 describes the implementation of the prototype and section 5.3 presents the results from the comparison.

5.2 Implementation

This section presents the results from the implementation phase. It is divided into client side and server side section to provide a better overview.

Figure 5.2 shows the resulting architecture after the implementation phase.
5.2. Implementation

Even though the theoretical results from this thesis is expected to be independent on what type of HMD client is used, the client part of the prototype was only implemented on Google Glass. This was due to the fact that this was the only available client hardware at the commencement of the thesis project. However, as presented in section 3.4, all of the present state of the art HMD devices run an Android operating system which would make the client prototype code portable to other HMD devices as well.

Since Google Glass is a rather new product the first step in the implementation phase was to explore how the product worked in terms of information presentation and interaction techniques. The available Software Development Kits (SDKs) were also examined. Google Glass supports all native Android functionality, currently Android API level 19 as well as a small library called Glass Development Kit (GDK) with Google Glass specific functionality.

5.2.1 Client Side

The first idea to be able to provide AR functionality was to use the library ARToolkit [30]. ARToolkit is a rather low-level AR library that provides reusable classes that make Augmented Reality programming easier. However, since the AR functionality is only a small part of this thesis project it was a risk that implementing AR from scratch using a low-level library would take much time while not contribute much to the research questions. Instead, development time was shortened by using a suitable Android AR framework that could be used directly. After some research it was decided that the Metaio SDK [31] was a suitable framework. Metaio is an extensive toolbox with advanced AR capabilities that supports multiple platforms. Metaio supports both marker-based and markerless tracking techniques. Marker-based tracking can
be achieved using quick response (QR) markers or images. Markerless tracking can be achieved using face detection, 3D CAD models or using a 3D map.

As a first approach of the rendering capabilities of Google Glass, marker-based tracking using QR-markers was implemented. This method worked well on the Google Glass even though rendering showed to be slightly slower than on a modern Android smartphone. However, running the AR app caused high battery drain and the glasses became very hot. There are also some aspects making the QR-marker technique unsuitable for usage in a vehicle maintenance context. This method would require all components that should be augmented with 3D models to have a QR code placed on them. In a real context there would be a large number of components, from several hundred to several thousand different components. Also, the QR-markers would quickly be soiled with dirt and grease making them undetectable from the camera.

The Metaio SDK also supports tracking based on a 3D map that could be created from a physical object. The object is simply analyzed using an off-the-shelf smartphone application [32] which creates the 3D map directly. The 3D map is then loaded into the Metaio SDK and the points in the cloud are compared to points detected by the camera in real time. If the similarity meets a specified threshold the 3D model is rendered on top of the physical object.

A 3D map of the SCR test rig was generated as seen in Figure 5.4, using the entire rig instead of just single components resulted in a more dense 3D map which means a more reliable tracking. However, when
the 3D map tracking technique was tested on Google Glass it was with poor results, the 3D object was not rendered in front of the rig. When the application was run on a smartphone, the tracking worked well with the 3D object correctly rendered throughout the entire test and from several different positions. This is probably a combination of the fact that the camera on Google Glass is not good enough and the processing power is too low. It is recommended that the 3D cloud is generated from the same device that the AR application is intended to run on. This is due to the fact that different devices have different camera parameters such as resolution, focal length and white balance causing different cameras to find 3D features at different positions. Currently, the application used to generate 3D maps cannot run on Google Glass but was instead generated from an Android smartphone. The difference in camera parameters between Google Glass and the Android smartphone is probably also a limiting factor to the 3D map tracking.

Because of the poor tracking result on Google Glass, the AR functionality had to be removed from the Google Glass app and instead demonstrated in a smartphone application. There is no doubt however, that this type of Augmented Reality will work good when the hardware of HMDs gets better.

The smartphone application was divided into two different parts that used two different ways of indicating what hose to detach. During the task where the hose on the pump should be detached a 3D model of the entire pump is rendered in front of the real pump with the hose connection painted in red. On the doser, an arrow pointing on the hose to
detach is rendered instead. Figure 5.5 shows the two ways that AR was used. In the questionnaire, the test users where asked which method that they thought was best, the result from the questionnaire is presented in section 5.3.

5.2.1.2 Limitations in Input and Visualization

The maintenance part of the existing program, SDP3, presents a large set of error code information to the user. Error codes have long textual descriptions of what may have caused it as well as what actions that should be carried out to fix the error. The troubleshooting guides also contains large amounts of text combined with pictures (see Figure 5.5: SCR pump and doser enhanced with AR)
5.2. Implementation

Since the display on Google Glass is small compared to a computer screen, the large amount of information from SDP3 is hard to present in a satisfactory manner. Instead, Google Glass applications should rely on short sequences of text that tells the user what to do. Some steps that contained large amounts of text in SDP3 were then divided into several, smaller steps in the Google Glass application which made them clearer and easier to understand. Figure 5.6 and Figure 5.7 shows how a step in the guide differs between the two applications.

Figure 5.6: Hose detachment step in SDP3

Some limitations were caused by the current version of the GDK. Since Google Glass is a rather new product it is reasonable to assume that the GDK will improve over the coming years. Currently, the GDK does not support lists that contain more than 5-6 items since these lists will overflow the screen and there is no scroll functionality implemented. To solve this issue a standard Android ListView was enhanced with gyroscope listeners which would cause the ListView to scroll when the user tilted his head. This method worked but for large lists there was problems in calibrating the sensitivity of the sensors so that a single item in the list could be selected easily. This functionality will probably be
5. Results

![Diagram of hose detachment steps in Google Glass]

Figure 5.7: Hose detachment step in Google Glass

implemented in the GDK in the future for easier development of Glassware.

There are also no good solution for character input on Google Glass, since the scenarios require the user to provide an id of the VCI3 to connect to this was a problem that had to be solved. One solution could be to connect a second device such as a smartphone or tablet where text can be entered and then sent to Google Glass. However, this requires the user to have another device available, something that is not always the case at the vehicle workshops. Instead, a custom input method was developed where the user can either say the VCI3 id out loud or enter one digit at a time by using the touchpad. The touch input procedure is shown in Figure 5.8, it uses the options menu in the GDK to make input possible. When the user taps on the touchpad an options menu is opened which contains numbers 0-9. The user can then scroll through the numbers by swiping the touchpad, the user selects a number by tapping on the touchpad again. The entered numbers is then shown in the GUI and the user can tap again to enter additional numbers. When the user is done entering the ID he can select “[continue]” from the options menu to submit the ID to the application. This method works acceptable but is cumbersome to use for a new user, it is also time consuming and requires many taps on the touchpad. For only numbers it is an acceptable method but if the ID could also contain letters it would be unsuitable. It is however the best method possible to implement with the current version of the GDK. Textual input on HMDs is a known problem and previous research has presented additional methods that are outside the scope of this project, such methods include gestures [33], AR keyboards [5] or more advanced, third party libraries such as the Minuum keyboard.
5.2. Implementation

5.2.2 Server Side

A fundamental requirement on the resulting system is that it should be integrated with the existing Scania software components. Therefore,
available documentation of the already existing Scania components was studied to explore how these components could be interacted with. As seen in Figure 2.2, to be able to interact with the CAN bus in the vehicle, connection to SCOMM is required through the SMAPi interface. Since the SMAPi interface is a .NET library, it was decided that the most appropriate approach to interact with SCOMM was via an ASP.NET server that could then easily include the SMAPi library. The ASP.NET server could then expose SCOMM functionality via web endpoints that could be accessed via the client application using HTTP requests.

The initial plan was to use Microsoft Azure\(^1\) for running the server side code. Using Azure Cloud Services the .NET server code could be run on a pool of virtual machines. The intention was that this could be used to easily provide scalability for the service as the work load increases. However, during configuration of the cloud services, some aspects hindering a feasible usage of Azure were detected. These aspects were issues of finding VCIs from outside Scania’s network as well as a good security practice of securing the web service that could be used with Google Glass. Instead of running the web server in the cloud it was agreed that the service should be hosted on a local machine for the prototype. However, for future usage when a system like this should be used in production, Azure is a highly suitable platform to run the system on. By using Azure the security and scalability requirements can easily be achieved. Azure offers many security mechanisms that can be added to the system such as embedded SSL- and TLS-cryptography, VPN-tunneling and Active Directory connections enhanced with Multi Factor Authentication. Microsoft also continuously performs penetration testing of these security mechanisms to guarantee a high security standard. Cloud services platforms are most often considered to offer better security standards compared to what a normal company can achieve\(^3,4\). Scalability in Microsoft Azure is achieved by using cloud services that are distributed over several instances where each instance comprises several elements such as worker roles, request queues, storage and caches. New instances can be added or removed either manually or automatically based on a number of requests or CPU load. The elements can also be scaled individually allowing for easy custom scalability. Based on the security and scalability features of Azure, it is a highly suitable candidate for hosting the system and achieving high quality standards.

The server was implemented as a RESTful server which receives HTTP requests. Following the RESTful design principles, the server was implemented to provide stateless services. During the case study a lot of people complained about how slow the current system (SDP3)

\(^1\)http://azure.microsoft.com/
was. This was solved by letting the server only read the requested data, compared to SDP3 that starts with reading all ECUs combined with signals and vehicle parameters which can give loading times over 10 minutes. At early stages of the implementation phase this was enough to make the server feel responsive but when longer call chains were implemented that had to be executed for every HTTP request it was discovered that the response time was too high. This was solved by letting the server save the open connections to the vehicle which reduced the response time for subsequent requests considerably.

5.3 Evaluation

The prototype was evaluated by comparing it to SDP3. This was done by letting 3 test subjects run the SCR troubleshooting guide from SDP3 and the other 3 from Google Glass with the smartphone companion application. Some of the subjects had prior knowledge of maintenance tasks while the others had never worked with maintenance before. Information about the subjects prior knowledge was collected from the questionnaire. The subjects were first asked to follow the troubleshooting guide and then asked to assess the system by doing the SUS-test as well as answering the questions presented in section 3.7. The time to finish the troubleshooting guide was measured for each subject and is presented below. Error rate (the number of times the subject detached the wrong hoses) was also intended to be measured but since no subject detached the wrong hoses error rate was omitted as a result. The time to complete the troubleshooting guide for each subjects is summarized in Table 5.1 below.

For subjects with prior maintenance knowledge the mean time for completion of the guide with Google Glass was 14 minutes and 19.5 seconds while 15 minutes and 45 seconds for the SDP3 users. For subjects without prior knowledge the mean time for completion of the guide with for Google Glass was 21 minutes and 45 seconds while 26 minutes and 38.5 seconds for the SDP3 users. In both cases the Google Glass was notable faster then SDP3.

There is also a considerable difference in time to completion between subjects with no prior maintenance knowledge in the two groups while the difference in time to completion between subjects with prior knowledge between the two groups are much smaller. This could mean that less knowledge of the context is needed when using the Google Glass application, possibly due to the usage of AR instead of unclear pictures. The researchers noted that the task of locating the hoses to detach during the tests was faster when using the AR application instead of the
5. Results

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time [mm:ss]</th>
<th>SUS score</th>
<th>Prior maintenance knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDP3</td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>26:07</td>
<td>77.5</td>
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</tr>
<tr>
<td>2</td>
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<td>90</td>
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</tr>
<tr>
<td>3</td>
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</tr>
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</tr>
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<td>4</td>
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<td>95</td>
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</tr>
<tr>
<td>6</td>
<td>15:40</td>
<td>95</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 5.1: Time to finish and SUS scores

pictures in SDP3, a fact that increases the strength of the claim that AR is better even further.

The assessment of the system was divided into two parts, first the usability was assessed by letting the subjects fill in a SUS-test. SUS-scores for each test subject is presented in Table 5.1, both systems had an average SUS-score that is considered excellent with the Google Glass application having a slightly higher score. The average SUS-score of SDP3 and Google Glass was 83.33 and 89.17, respectively. After the SUS-test the subjects were asked to answer a set of interview questions that captured more specific thoughts about the system. The answers were grouped into themes, which have been summarized for the two systems in Figure 5.9 and Figure 5.10 below.
5.3. Evaluation

Figure 5.9: Interview results on SDP3

![Graph showing interview results on SDP3]

Figure 5.10: Interview results on Google Glass

![Graph showing interview results on Google Glass]

5.3.1 Interview Results on SDP3

In the following subsections the themes presented in Figure 5.9 is presented in detail.

5.3.1.1 It was hard to locate the correct hose to detach

All test subjects in the SDP3 group stated that it was hard to understand which hose that should be detached. The subjects that did not have any
5. Results

prior maintenance clearly stressed this shortage but the more experienced subjects also pointed out that improvements could be made. More specifically, difficulties occurred when the subjects should compare the real component to the picture. The real component is often placed in a different position or angle than how it is illustrated in the picture.

5.3.1.2 The steps were unclear or hard to understand

Some of the steps in the guide caused confusion. Subjects stated that this was because of the large amount of text in that step, and that several actions were required before proceeding which increased the risk of error. Some of the steps required the subjects to both read the text and look at the picture, some subjects only read the text and missed the picture which did not give enough information to understand what to do. There should be a clearer connection between the pictures and the textual information.

5.3.1.3 Questions were asked in an inconsistent way

Confusion occurred due to the inconsistency in the way questions were asked in the text compared to how the subject was supposed to answer the question. For example, in the text the question was asked as: “Is the component intact?” compared to the question next to the drop down list where the user should select an answer: “Is the component clogged or damaged?”. This creates inconsistency in the application and could also lead to an incorrect answer for an inattentive user.

5.3.2 Interview Results on Google Glass

The subsections below presents the themes presented in Figure 5.10 in detail.

5.3.2.1 It was easy to locate the correct hose to detach

There was high satisfaction with the AR functionality and subjects stated that it helped them locate the hoses quickly. Subjects with no prior knowledge stated that the AR was very helpful when they did not know the name of the components mentioned in the text, then they could simply aim the camera at the SCR rig and see what component that was augmented.

5.3.2.2 The steps were clear and easy to understand

All subjects stated that they experienced the steps in the guide as clear and that it was easy to understand what to do. Several subjects emphasized that the step-by-step instructions gave an easy and summarized
description of what to do. This was probably due to the fact that some of the larger steps in SDP3 were divided into smaller steps when implemented on Google Glass.

5.3.2.3 It was hard to navigate the interface

Some subjects claimed that they had some problems understanding how to interact with Google Glass and how to navigate the interface. Confusion arose when the subject started to switch between controlling the interface with both voice commands and touchpad since the options menu look and behaves differently depending on if the user opened it by voice or touch. However, the subjects that only used voice commands experienced little or no confusion at all.

5.3.3 Additional Findings

In addition to the findings from the interviews the researchers also noted that the subjects in the SDP3 group had to move back and forth between the SCR rig and the PC when trying to locate the correct hose to detach, this was even more common between the subjects with no prior maintenance knowledge. These subjects tried to compare the pictures in SDP3 to the physical components mounted on the SCR rig. Because of this, locating the correct hose was more time consuming in the SDP3 group compared to the Google Glass group.

It was also noted that some subjects had problems with the AR application, the subjects had to hold the smartphone steady for several seconds before the AR object was rendered on top of the SCR pump or doser. Once the AR application had sufficiently rendered the object it was still sensitive for fast movements which could cause the application to lose track of the target. However, once the object was rendered and tracking worked, the subject could easily locate the correct hose. Object tracking is an area that is still hard to implement sufficiently for usage in a finished product, the limitations lies in the hardware and the algorithms used but based on how the area has advanced during the last 20 years both hardware and algorithms will probably be good enough within the near future.

The smartphone application used two different ways of indicating what hose to detach, the detachment of hoses from the SCR pump was augmented with a 3D object of the entire pump and detachment from the pump was augmented with an arrow, see Figure 5.5. During the interviews the users who had used the Google Glass application was asked which method they thought was working best, two out of three subjects preferred the arrow over the 3D model of the pump. The subjects who preferred the arrow claimed that the 3D object over the pump was un-
5. RESULTS

clear and that it sometimes looked as another hose should be detached. The subject who preferred the pump stated that the arrow could point to the hose next to the hose that was actually intended.
6 Discussion

6.1 Results

During the implementation and evaluation phase several important conclusions were drawn. The hardware in Google Glass was not good enough to perform object tracking, the performance of the glasses dropped significantly when trying to locate objects. Google Glass has almost identical hardware as other state of the art HMDs which means that other HMDs probably would suffer from the same problem. Previous studies [2], [3], [16] that have evaluated HMDs and AR have used marker-based tracking which reduces the computer power needed to locate objects and because of this they did not suffer from the same problem. With the current advances in both hardware and algorithms for object tracking it is only a matter of time before this functionality can be implemented in a satisfying manner on an off-the-shelf HMD.

The 3D map that was used for the object recognition was created by filming the object from multiple angels. If a company was to implement this type of system for something as big as a truck, a more automated way to create 3D maps is required. Metaio, which was used in this project has support for creating 3D maps from 3D models, unfortunately the maps created from this technique were not precise enough. However, if Metaio or any other AR library offered functionality like this that is good enough, the whole process of creating 3D maps could
be automated. Most manufacturing companies already have 3D models for all their products which could be used to create the 3D maps.

One distinct difference that became clear when observing the test subjects was how many times subjects in the SDP3 group had to move between the rig and the computer to read information from the screen. The subjects had to do this every time they should proceed to the next step in the guide. Very often they also forgot information or were not sure if they had read the guide right and had to move back to the computer and check again. SDP3 often contains much text in each part of the guide which can make it hard for mechanics to remember all steps required. On the other hand, if the parts were shorter the mechanic might have to move even more often to the computer. HMDs solves this problem, it can always be worn by the mechanic, removing the need to move from the working area to read information. Not having to move to read information also enables the option to have fewer steps in each part of the guide, reducing the chance that a step is misunderstood or causing confusion.

Subjects in the prototype group spent shorter time locating the right hoses in steps that had AR-support. Subjects using SDP3 had to figure out how the pictures in the guide corresponded to the physical object on the rig. Subjects in the SDP3 group with workshop background often used the picture in the guide to locate the component and then identified the right hoses from the textual description, but even with their prior knowledge of the system they had problems locating the right hoses. Even though the prototype group spent less time locating the hoses, there were still some complications, especially with the tracking. In order for the application to render the object, the subject had to hold the device still for a few seconds. If the subject performed any sudden movements while the objects was rendered the tracking was lost. However, when a subject managed to render the object and keep it they quickly located the right hoses. This means that with better tracking or possible better hardware the tracking issues could be resolved and AR would have been even more superior than text guides. Better hardware would also allow the AR parts of the guide to be added to the HMD reducing the time needed to perform these steps even more. It is also easier for users to hold their heads steady compared to their hands, making HMDs a better choice for AR functionality.

Comparing the time needed to complete the task shows that the prototype system was quicker than SDP3. The difference is bigger when comparing subjects with no workshop background but the time difference still exists for all subjects. None of the subjects had used HMDs before and they had problems controlling the device. If workers were to use HMDs in their daily work they would learn the navigation and interface and probably be even quicker.
The prototype’s average SUS-score was 89.17 while SDP3s was 83.33. Over 80.3 is considered excellent and both systems reach well over that. SUS-score is a common way to measure usability and the result from the SUS-score indicates that the test subjects thought that the prototype system was easier to use. However, it should be noted that comparing a prototype to a finished product may not give the whole picture. The finished product contains much more functionality which could make it hard to keep an easy to use interface when having to fit in all functionality for a full program. On the other hand an existing product have existed for some time and have also been tested more thoroughly. SDP3 in this case, is also a PC based program with an interface most people are familiar with while Google Glass has a new type of interface that none of the subjects used before which could lead to a lower SUS-score compared to SDP3.

6.2 Method

The case study plays an important role in this project as it gave the starting points for how the research questions should be answered. Several steps were taken to increase validity and reliability of the case study.

- Interviews and observations were based on multiple subjects. Basing conclusions on multiple subjects increases the chances of finding problems concerning all employees.

- Two different methods to collect data were used, interviews and observations. Using multiple methods to collect data decreases the chance of interpretation effects from one single data source. Drawing the same conclusion from multiple data sources increases the validity of the conclusion i.e. data source triangulation \([23]\).

- Two researchers where present during the observations and interviews to achieve observer triangulation and therefore decreasing the risk of biased assumptions.

Some points that contradict the validity and reliability of the case study can also be raised. The case study was carried out at one workshop. All Scania workshops use the same computer programs when performing troubleshooting. But it is possible that this workshop is not representative for other Scania workshops. The duration of the case study was limited to one day and as a result the risk for observer caused effects increases \([26]\). The researchers had no prior knowledge from conducting case studies. As a step to reduce the impact of limited experience conducting case studies, all interviews where semi-structured instead of unstructured which otherwise would have been a good option.
6. DISCUSSION

for exploratory research. Having used the same questions for all subject also makes it easier to replicate the case study.

At the start of each test a short presentation of the scenario and a demonstration of the prototype was held. No guidelines for how the presentation and the demonstration should be performed or consist of were established. Because of this, prior knowledge of subjects before the test may have differed and might have affected the results. It also makes it harder for other researchers trying to replicate the tests. All tests during the evaluation phase were carried out on a test rig. On the rig, the SCR-system is fully visible and this might not be the case on a truck. Components could be located behind other components making it harder to locate and see them. It is not certain that test on the rig correspond well to the same task on a truck and could be a threat to the validity of the evaluation. The test subjects have different backgrounds, while some are workers at Scania workshops others are white-collar workers and may have limited experience with this type of tasks. In the evaluation part of the report, subjects with workshop background are clearly distinguished from subjects without workshop background to not skew the results. Subjects with workshop background are probably the most interesting as they are the primary user of this type of system. Subjects without workshop background are still an important test group and could simulate using the system as a learning tool.

All papers used as references in this report are well cited. Some of them define the area and other papers build on the findings of others. All theory is based on at least two different papers, often more. Gathering information from different authors reduces the risk of only reflecting one person opinions on the field.

6.3 Work in a Wider Context

The use of HMDs is tightly linked to privacy which is a hot topic. The increasing use of devices that can record video and take pictures makes it easier for surveillance. People can be recorded without their knowledge and this raises integrity questions. HMDs is even more discreet to use in this case than cellphones and other devices. To record someone with a cellphone the user has to hold up the phone which could be a good indicator for the victim that it is being recorded. HMDs on the other hand, only require the user to turn the head in the direction of the victim being recorded and it is a lot harder for the victim to notice. HMDs could also make it possible for companies to monitor their employees. The work in this report has mostly been regarding usability of HMDs and the possibilities and limitations they have. From another perspective it can also have positive effects on safety for workers doing any physical
labor. If a PC program is used and the user has moved away from the computer, warnings will not help much. If HMDs were added to other mandatory safety equipment the user would always have a screen located right before the eyes and warnings would be almost impossible to miss.
Conclusion

Earlier studies on HMDs in maintenance contexts have been promising. It has been shown that HMDs are more portable than PCs and offer other ways of interaction than via mouse and keyboard. This lets the worker have both hands free for physical tasks and the information presented by the HMD is always reachable for the worker without having to move between the vehicle and the computer. HMDs are also considered better for AR functionality since the display is placed directly in front of the eyes of the user. This argument has to be explored and tested not only in theory but also in practice to see how they can be utilized with an off-the-shelf product.

During the implementation of the prototype some problems occurred, both concerning the current hardware and HMDs in general. Firstly, the hardware on off-the-shelf HMDs is not good enough for markerless tracking. Markerless tracking is important when trying to realize this type of systems for complex vehicles where components can be hidden. The processor and camera on current state of the art smartphones work nicely with markerless tracking meaning that when HMDs hardware reaches the same standard they would be fully functional for markerless tracking. In a fully developed system the need for text input will most likely occur and is something current HMDs lack. Another challenge for developers of HMDs is the power consumption. For HMDs to be realistically considered for maintenance purposes the battery life would have to be improved significantly, a minimum of half a day be-
between charging is needed, letting the worker complete a work session without having to charge the HMD.

The second research question was concerning the efficiency and satisfaction of HMDs in a maintenance context. The conclusions presented here are based on the tests conducted on the rig and the interviews held after the tests. It was clear that the prototype group was more efficient, for subjects with prior maintenance knowledge the mean time for completion of the guide with Google Glass was 14 minutes and 19.5 seconds while 15 minutes and 45 seconds for the SDP3 users. For subjects without prior knowledge the mean time for completion of the guide with Google Glass was 21 minutes and 45 seconds while 26 minutes and 38.5 seconds for the SDP3 users. Using a HMD instead of a computer let the subjects stay at the rig for the whole duration of the test without having to go to the computer, for the same reason the guide could have less information in each step reducing the chance for the subject to misunderstand the step. The steps that required the subjects to locate components on the rig was a lot quicker with the help of AR, especially for subjects with less knowledge about the SCR system. With vehicles that are becoming more and more complex it will be hard for even the most skilled workers to keep up with all new systems added to the trucks and AR could then become an even more usable solution.

The SUS-score and the result from the other interview questions were also in favour of the prototype which indicates better usability. The prototype received an average SUS-score of 89.17 which is considered excellent while the SDP3 group got 83.33. Considering that subjects had never used HMDs and that the interface and how you interact with the HMD was new to them, that the prototype group still got a higher SUS-score is rather impressive. All the subjects could see the benefits of using HMDs for this sort of tasks, that workers saw the benefits could make it easier to incorporate HMDs in workshops.

With the theoretical benefits that HMDs enable and the results from this report backing those up, the researchers believe that HMDs can provide value in workshops. Increased usability, efficiency and the positive attitude of workers is all compelling arguments for the introduction of HMDs into the workshops. Also, since HMDs are still a growing market with many interesting products just around the corner, it is reasonable to assume that the issues of current off-the-shelf HDMs discussed in this thesis, will be solved within the near future.
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