Using Augmented Reality as a tool for troubleshooting separator alarms

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Abstract

Some say that the fourth industrial revolution is here now that machines can communicate with each other. This combination of Internet of Things (IoT) with industrial machines has been labeled Industry 4.0. Alfa Laval, manufacturer of liquid separators, together with B&R, an industrial automation company, want to explore the possibilities with Industry 4.0 and especially how Augmented Reality (AR) can be used as a tool when troubleshooting separator alarms.

This master thesis encompasses the development and evaluation of an AR application for troubleshooting separator alarms. The final AR application shows instructions to the user and highlights the corresponding components as 3D models in AR. User tests showed that the application can be useful for people without experience of troubleshooting separator alarms. Additionally, the tool can indirectly reduce the workload for expert service technicians since they don't have to show up and troubleshoot the simpler alarms. In the future, a tool similar to this can be used during the training process of prospective service technicians.

Keywords: Augmented Reality, Usability, Troubleshooting, Separator, Industry 4.0, Interaction Design

Sammanfattning

Vissa säger att den fjärde industrirevolutionen är här nu när maskiner kan kommunicera med varandra och kombinationen av Internet of Things (IoT) med industrimaskiner har kallats för Industry 4.0. Alfa Laval, tillverkare av vätskeseparatorer, tillsammans med B&R, ett företag inom industriell automation, vill utforska möjligheterna med Industry 4.0 och särskilt hur Augmented Reality (AR) kan användas som ett verktyg vid felsökning av separatorlarm.

Det här examensarbetet omfattar utveckling och utvärdering av en AR-applikation för felsökning av separatorlarm. Den slutliga AR-applikationen visar instruktioner till användaren och framhäver motsvarande komponent som en 3D-modell i AR. Användartester visade att applikationen kan vara användbar för personer utan erfarenhet av felsökning av separatorlarm. Dessutom kan verktyget indirekt minska arbetsbelastningen för erfarna servicetekniker eftersom de inte behöver dyka upp och felsöka de enklare larmen. I framtiden kan ett verktyg som liknar detta användas under utbildningen av blivande servicetekniker.

Nyckelord: Augmented Reality, Användbarhet, Felsökning, Separator, Industri 4.0, Interaktionsdesign

Acknowledgements

Contents

Contents

List of Figures

List of Tables

Abbreviations

IoT Internet of Things

AR Augmented Reality

UI User Interface

UCD User-Centered Design

PLC Programmable Logic Controller

GVDS Google Ventures Design Sprint

TCP Transmission Control Protocol

CHAPTER 1

Introduction

Industrial progress has always come hand in hand with new technology. The first step was the steam engine, followed by electricity and later on computers. Now it's time for the next big step: combining industrial machines with IoT, which has been labeled Industry 4.0.[1] Today, machines and devices can all be connected to each other, share information and can make decisions on their own without the help of humans. This is the industrial revolution with an ambition to synthesize the real and virtual worlds.

One interesting new technology in this Industry 4.0 context is Augmented Reality (AR). AR combines interactable virtual objects with the real world in real-time, presenting an enhanced version of reality to the user.[2] Since AR and Industry 4.0 both are rather new concepts, the area where they intersect is relatively unexplored. In recent years, application stores have been populated with a modest amount of AR applications, such as IKEA Place, allowing anyone to experience the new technology with their own smartphones.[3] The reason for this boom of AR applications can be traced back to both Apple and Google releasing native AR support and development kits for their respective mobile operating systems last year.[4][5]

In the professional world, the use for AR has been researched for quite some time. Studies have been made on how AR can be utilized during high precision procedures such as surgery.[6] Others have researched how to apply AR in an industrial maintenance setting and concluded that it can improve the efficiency in performing maintenance.[7] The world leading separator manufacturer Alfa Laval, together with the industrial automation company B&R, has shown interest in exploring the possibility of using AR with their products.[8][9] Specifically, they want to test AR as a tool for

helping people without experience to troubleshoot separator alarms.

1.1 Purpose

The purpose of this master thesis was to explore the possibilities for AR as a tool in the troubleshooting process of liquid separators, and evaluate whether or not people without expert knowledge of the process felt that this tool could assist them when troubleshooting separator alarms. With a mobile AR application, users should be shown multiple instruction sequences of separator alarms. These instruction sequences should provide users with all the knowledge they need to figure out how to troubleshoot the specific alarms.

In addition to the main purpose, two sub-questions that tangent the main purpose were also asked:

- Could AR be used to reduce the workload for well trained service technicians?

- Could AR be used during the training process of new service technicians?

1.2 Scope

Due to this project being a master thesis that should last about 20 weeks, the scope of had to be well defined. To create a functional application we needed to set some limitations for the prototype in order to focus our work and not end up with a lot of half finished functionalities.

- The mobile application was developed for the iOS platform and first and foremost for the iPhone. Even though it can run on an iPad, it has not been a priority when making design choices.

- A limited number of alarms have been chosen to showcase the idea. These alarms have linear troubleshooting processes to avoid creating unnecessarily complicated steps in the application. When designing the instruction sequences for the specific alarms, the size of the components that should be visualized has been taken into consideration to avoid relying on perfect 3D-models to represent the physical counterparts.

CHAPTER 2

Theoretical Background

In this chapter previous work, related literature and theories are presented to provide a theoretical background to the project.

2.1 Industry 4.0

Industry 4.0 is a term that has been used to describe the next big leap of technological advancements in the industrial field. It is called 4.0 because it has been preceded by three large inventions. The first invention was the steam engine, which kick started the industrial revolution. This was followed by electricity and the assembly line, which made the industry more effective. The third invention was computers which created the possibility of automation.[10] Now, Industry 4.0 has just started to emerge and it can be attributed to the invention that is the Internet of Things (IoT), which creates the possibility that each machine in a manufacturing process is a smart device and each machine can communicate with each other. This essentially creates a smart factory. The four industrial revolutions can be seen in Figure 2.1.
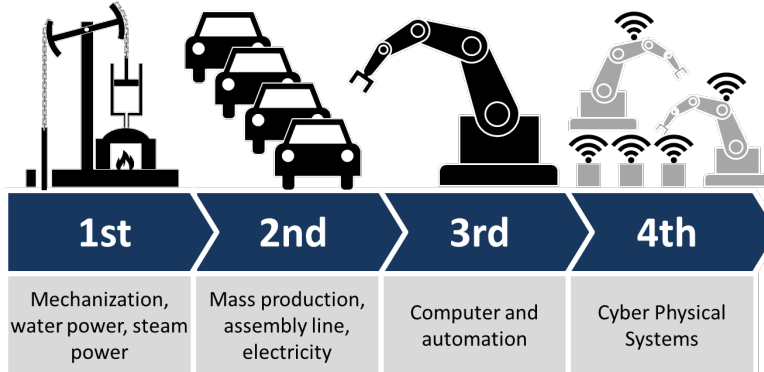
Figure 2.1: The four industrial revolutions. Credit to Christoph Roser at AllAboutLean.com (CC BY-SA 4.0).[11]

Hermann, Pentek and Otto presents four design principles regarding industry 4.0: [1]

- Interconnection: All machines, sensors and devices are connected through the Internet of Things, together with the Internet of People (IoP) they form the Internet of Everything (IoE).

- Information transparency: Because this is a fusion of the physical and digital world it requires a new level of information transparency. The physical data is copied into the digital world via sensor data and digital plant models. Context-aware information is a key to allow the IoE to make appropriate decisions each time.

- Decentralized decisions: By having interconnection together with transparency, each component can combine global information with local information and thus decentralized decisions can be made. This is important to improve decision-making and the overall productivity

- Technical assistance: When there are many interconnected components that make autonomous decisions, the role of the humans become more complicated. To mitigate the situation, technical assistance is needed to visualize information in such a way that humans can make informed decisions as well as solving time sensitive problems that may occur.

2.2 Augmented Reality

Augmented Reality (AR) is a technology where virtual objects are combined with the real world in real-time to enhance the world around us. This can be achieved using various types of displays, such as Head Mounted Displays, smartphones and stationary screens.

AR is described by Ronald T. Azuma [2] as having three defining characteristics:

- Combines real and virtual.

- Interactive in real time.

- Registered in 3D.

There are two distinct ways to create the mix between the real world and the virtual world: [2]

- Video see-through: Using a camera to capture the real world and then superimpose the virtual objects onto the image.

- Optical see-through: Using a holographic display to render the virtual objects which enables the user to see the real world through the display.

One problem with AR is the so called *Keyhole effect* which is the result of using display technology with a limited field of view. It's called the Keyhole effect because of the limited view the user gets of the augmented world, which makes it feel like they're looking through a keyhole. This effect is most apparent when using AR with video see-through technology.[12]

2.3 User-centered design

User-Centered Design (UCD) is an iterative design process where the users and their needs are considered in every step of the process.[13] Hence, the designer must understand the end users needs, knowledge, and previous experiences, as well as the circumstances in which the service or product will be used. Since UCD is an iterative process, each cycle contains a set of activities that need to be completed before you can start the next iteration. There are four activities in each iteration: observation, ideation, prototyping and user testing. Observation is when the users are observed while they use the system to try to understand the users and their behavior. Ideation

is when new concepts and different ideas are discussed and explored. Prototyping is when ideas and concepts are implemented and user testing is the activity where users test the prototype and provide feedback. The four phases in each iteration are illustrated in Figure 2.2.
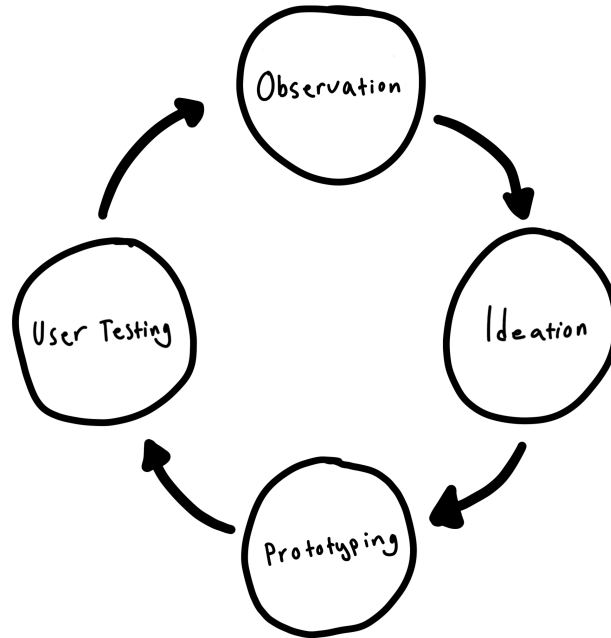
Figure 2.2: The four phases of each iteration in UCD.

2.4   Gestalt principles

When working with visual design it's imperative to know about the Gestalt Principles and use them to your advantage. The idea of the existence of a number of principles or laws regarding the human visual perception originates from the 1920's and the psychologists Max Wertheimer, Kurt Koffka and Wolfgang Kohler.[14] In his book Principles of Gestalt Psychology, Kurt Koffka stated that "the whole is something else than the sum of its parts", which epitomizes the gestalt principles.[15]

The following five principles were declared by Wertheimer in his text "Laws of organization in perceptual forms":[14]

2.4.1 Proximity

The first principle Wertheimer presents is that objects are grouped by proximity, meaning that we perceive objects that are close together as a distinct group. This can be seen in Figure 2.3.

Figure 2.3: The law of proximity

2.4.2 Similarity

Objects with similar visual properties, like color and shape, are recognized as belonging to the same group, as can be seen in Figure 2.4.
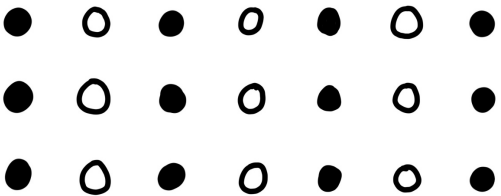
Figure 2.4: The law of similarity

2.4.3 Common fate

We perceive objects moving in the same direction at the same speed to be grouped together, which is illustrated in Figure 2.5.
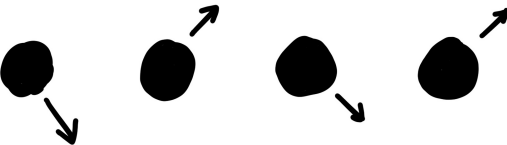
Figure 2.5: The law of common fate

2.4.4   Direction/Continuation

Objects that appear to be placed on a continuous path, appear to have the same direction or appear to be part of a sequence, are perceived to be part of the same group. This can be seen in Figure 2.6.
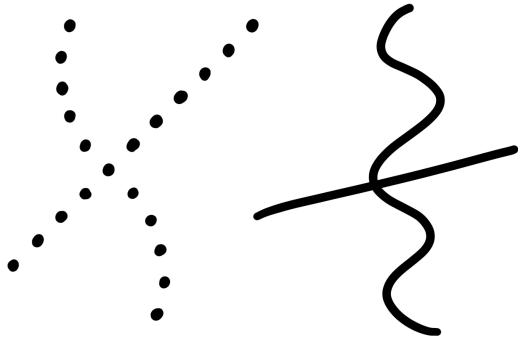
Figure 2.6: The law of continuity

2.4.5   Closure

Our minds fill in the gaps between objects that are grouped by direction and continuation. This way we can perceive shapes that aren't actually there and this is illustrated in Figure 2.7.
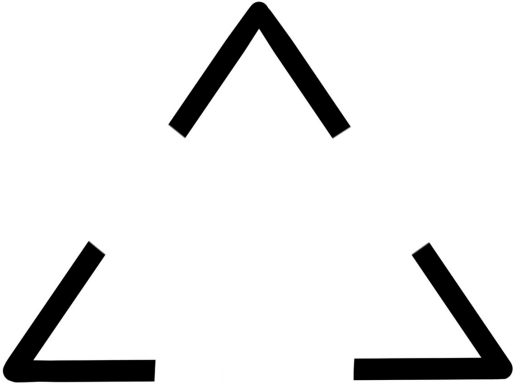
Figure 2.7: The law of closure

2.5   Donald Norman's design principles

In his book *The Design of Everyday Things* Donald Norman talks about experiences and how great design produces great experiences. However, it's important to acknowledge that an experience is very much subjective and can be hard to measure.[16]

There are a lot of things that affect our experience with a product. For example, one of the most important aspects is figuring out how to use a product. Donald Norman calls this *discoverability* and says that it derives from five fundamental psychological concepts: *affordances, signifiers, mappings, feedback* and *constraints*. Norman also adds a sixth principle — *the conceptual model.*[16]

2.5.1   Affordances

Affordance is the connection between an object's characteristics and how a person can actually utilize that object. For example a button has the property of being pressed down and therefore affords pressing. Affordance can still vary between different people, a heavy object affords lifting to a physically strong person but not to a physically weaker person. Affordances are only effective if they can be perceived. If they can't be perceived then they can't afford their interaction possibilities, and in those cases there needs to be some way of signaling their presence, Norman calls this *signifiers*.

2.5.2   Signifiers

While affordances are great when it comes to what kind of interactions are possible, it does not work when it comes to explaining specifically where this interaction should be done. For example, a touch screen affords the interaction to tap the anywhere on the screen and not on specific areas of the screen. Because of this, Norman introduced the term signifier which instead focuses on exactly where an interaction can be performed. If we take the touch screen again as an example, a typical signifier would be to highlight specific areas of the screen where the user is supposed to interact with it.

2.5.3   Mapping

Mapping is actually a term that is taken from mathematics and it is the relationship between two groups of items. The most logical way of mapping is to utilize the spatial correspondence between the items, for example when

a steering wheel is rotated clockwise the car will turn in the same direction as this movement, i.e. to the right.

2.5.4   Feedback

When an action is performed there needs to be some kind of indication that the action has been noticed and is being processed. The feedback that is given has to be carefully thought out and if the feedback is delayed for too long the user will lose interest or think that their action was not noticed. Feedback also has to be given with the right amount. If too little feedback is given it can be easily missed, but too much feedback can become annoying as well.

2.5.5   Constraints

The act of determining how to operate something you have never seen before can be quite difficult. If the designers have been thoughtful with their constraints, i.e. how to *not* interact with the object, the amount of interactions that are possible are narrowed down and this limits the risk of the user making errors when they try to use the object.

2.5.6   Conceptual model

The conceptual model, which Norman hints at being perhaps the most important aspect to having a good experience, could be described as the explanation of how something works. This explanation is often a simplified version of how something actually works, but it provides the user with a way to easier understand how the thing works and how to use it properly.

2.6   Diegesis

Diegesis is a concept used in storytelling and narrative development as a way to refer to the world where the story unfolds. Specifically, everything happening in the world where the story takes place that the characters can experience is described as diegetic and everything else as non-diegetic. An example of something diegetic from the art of filmmaking is a dialogue between two characters taking place in front of the camera, while examples of non-diegetic elements in film are subtitles and the soundtrack.[17]

When talking about diegesis in a video game UI context there are two additional terms that need to be mentioned: meta UI and spatial UI. These

two concepts are part of the non-diegetic UI. Meta UI is usually two dimensional and often complies with the visual style of the diegetic world in the game without being a part of it spatially. Spatial UI is when non-diegetic UI elements are presented in 3D.

CHAPTER 3

Technical Background

In this chapter, an introduction to the technical components of the project is given. This includes both the hardware components of the project as well as the frameworks that are used in the AR application.

3.1 ARKit

ARKit is a framework developed by Apple which utilizes the camera together with motion sensors to help developers create AR content within mobile applications. By combining device motion tracking, camera scene capture and advanced scene processing ARKit has excellent capability of creating augmented reality experiences for iOS devices.[18]

With the release of ARKit 1.5, Apple further improved its functionalities by making it possible to not only find horizontal surfaces, but vertical surfaces as well. The second critical addition was image recognition which makes it possible to recognize specific images such as paintings or brochures and use this as an anchor point to render AR content.[4]

3.2 SceneKit

SceneKit is a 3D framework developed by Apple. The API available in SceneKit is relatively high-level compared to similar frameworks from other companies. With SceneKit all you have to do is to give a description of the content you want in a scene and define which actions and/or animations you want the content to perform.[19]

The framework combines this descriptive way of creating content with a physics engine and a particle generator. This means that a scene can be created with geometry, materials, lights and cameras. By describing the changes to these things we can also animate it.[20]

3.3   Separator

A separator is a machine which is used to separate liquids. For example separating the more thick cream from the thinner milk. The main component of a separator is a quickly rotating container which utilizes the centrifugal force to push the thicker liquid outwards and the thinner liquid is kept in the center of the container. A separator can also separate sludge from liquids. An example of a separator can be seen in Figure 3.1.

Figure 3.1: An Alfa Laval separator. (Taken from [21])

3.4   Programmable Logic Controller

A Programmable Logic Controller (PLC) is a computer specialized for industrial use, and has been adapted and created to control the manufacturing process. It should also be easy to program and reprogram the PLC so it can be adapted to different situations. These programs that are running on the PLC are all executed in clock cycles, and if a program has not been executed completely during the specific clock cycle it will be dismissed. The overall system is deterministic, so when a specific event happens it should always render the same outcome, without any randomness. And lastly, a PLC has to have very good process fault diagnosis. This means that the PLC has to be able to activate an alarm when something is faulty.[22]

If something breaks down in the manufacturing process it renders two scenarios: either the PLC works properly and stops the production (i.e. it fulfills its intended purpose), or the PLC itself is faulty which could result in a catastrophic failure.

Method

This chapter presents the methodology that was employed during the course of this master thesis. The project was divided into four separate phases. The first phase was the investigation phase which included a literature study with focus on AR and Industry 4.0. It also included a visit to the Alfa Laval laboratory in Tumba. The second phase was the conceptual phase, followed by the development phase which is explained in further detail in chapter 5. The last phase was the verification phase which focused on user testing of the AR application prototype created during the project.

4.1 Investigation Phase

The initial phase began with the literature study which focused on AR and Industry 4.0. For the AR the focus was on hand-held AR as well as AR in an industrial context.

A visit to the Alfa Laval laboratory in Tumba was also conducted. This was done to gain a deeper understanding of how the troubleshooting process of the separators works today. A quick introduction to how the separators work was also given to further deepen the understanding of the current process and how it could be improved. Currently when the separator breaks down, a *PLC* that is connected to the separator will sense the fault of the separator and display the alarms on a small screen showing the alarm code and description.

If the person responsible for the machine can't troubleshoot the alarm themselves, they can either look it up in a large instruction manual containing

the instructions for each and every alarm that can happen on the separator, or they can contact Alfa Laval to get expert assistance from a service technician. The two alternatives are quite different but could perhaps be improved by the same solution. If the instruction manual was improved with for example AR, more alarms could be fixed without the help of service technicians. Which would make the whole operation more effective and also have shorter downtimes.

With the application, the idea is that the person troubleshooting an alarm shouldn't have too look at the small screen to see which alarms that are active and how to troubleshoot them. This means that there has to be a connection between the PLC and the AR application to be able to retrieve the active alarms of the separator.

Consequently, the system would consist of three vital parts (also seen in Figure 4.1):

- The physical separator.
- The PLC that has all the alarm information.
- The AR application that contains all the troubleshooting information.

Figure 4.1: The three components of the system: Separator, PLC and AR application.

4.1.1   Explain why iOS ARKit

4.2   Conceptual Phase

Based on the initial phase where a lot of the current issues with the troubleshooting process were identified, a body- and brainstorming session was conducted were all ideas were embraced that could improve on these issues. These ideas were written down and saved for later. The conceptual phase was a part of the first iteration in the development process.

After the initial ideation, a modified Google Ventures Design Sprint (GVDS) was started. The first step in this sprint was to write down all potential problems that might emerge when using the application. Among these potential problems, five of them were chosen as being the most important. These five problems were used as a base for the next phase of the sprint where the problems were rephrased as sentences that began with "How might we...". This way of wording the problems puts people in another mindset making it easier to solve them.[23] Continuing along the GVDS, potential solutions to each of the "How might we..." sentences were written down and compiled for use in the next phase of the sprint. The most important "How might we...'s can be seen in Figure 4.2.
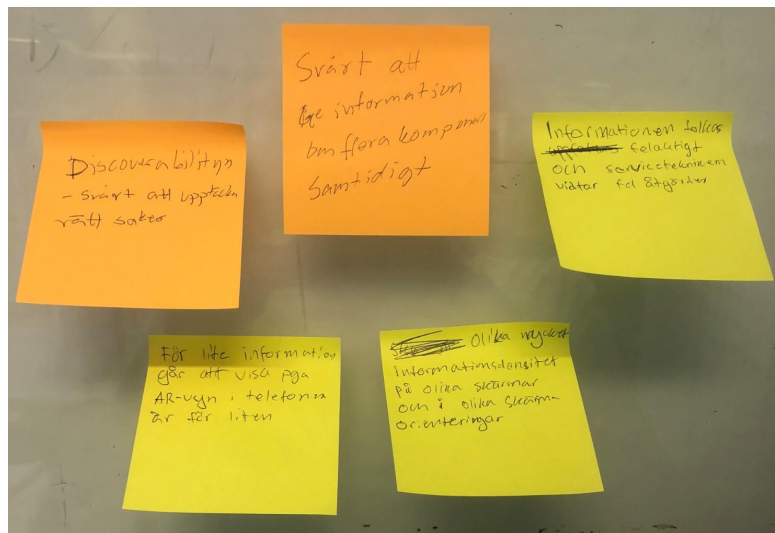
Figure 4.2: The most important "how might we..."s.

The next step in the conceptual phase was storyboarding, where focus was on the *non-diegetic* parts of the UI. With the potential solutions from the previous phase, a conceptual design of the UI was drawn on a whiteboard. Several ideas were explored and drawn up, with the final drawing of the conceptual UI being photographed for documentation purposes. Using the simple drawings, a Mid-Fi interactive prototype of the non-diegetic UI was implemented in Figma.[24]

Following the conceptual design of the non-diegetic UI, work began on the conceptual design of the non-diegetic spatial UI. Since the discoverability

of specified components of the separator is crucial to the functionality of the app, a lot of focus was initially put on exploring ways of highlighting components. Using Norman's design principles and the gestalt principles, an extensive number of approaches to highlighting were developed during a brainstorming session. Eight of those were chosen to be a part of a demonstrating application that was used during a user test.

4.3   Design and Development Phase

The development phase of the project was largely conducted in iterations that lasted around two to three weeks and employed the UCD principles. This meant that each iteration contained ideation, prototyping, user testing and observation. This structure was followed in each iteration, except the last iteration which included a larger user test. This user test was a part of the verification phase, which is explained in further detail in the next section.

4.4   Verification Phase

In the final phase of the project the troubleshooting application needs to be tested and evaluated. This evaluation was done by conducting a user test at the Alfa Laval test laboratory in Tumba. The aim with the test was to see if the prototype can be a useful tool for service technicians with no or limited prior knowledge of the troubleshooting process. In preparation for the user tests a test plan was created, which can be found in appendix A.

4.4.1   Preparation

The selection of participants was not strict, but the goal was to have testers with a varied level of expertise of the separators and their troubleshooting process. The amount of participants was not a top priority for this test. As described by Nielsen [25], 15 participants normally find about 99% of all usability problems in an application during usability testing (see Figure 4.3).
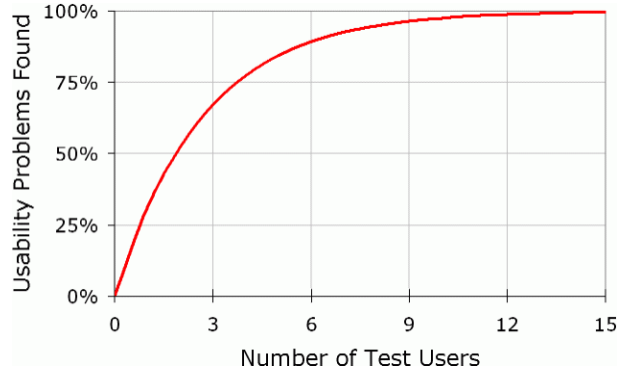
Figure 4.3: The probability graph for usability testing (taken from [26]).

Nielsen also mention that it's preferred to employ an iterative process and do three user tests with five participants in each.[26] Because a smaller user test within each iteration of the development phase was conducted, the user test in the this verification phase should emphasize on getting test participants that are appropriate and can provide useful insights and feedback on the application. The main goal with the tests was to evaluate if AR can assist the troubleshooting process for users with no prior knowledge of separator troubleshooting. Based on this, two questionnaires were created that focused on the quantitative data collection. The first questionnaire focused on the testers pre-existing knowledge of the separator and the troubleshooting process. A question about if they have used AR before was also asked. The second questionnaire was meant to be answered after the test and focused on their confidence regarding the troubleshooting process, as well as to what extent they thought that the application could be used. To complement the quantitative data, an interview was also designed to get qualitative data as well.

4.4.2   Execution

The user tests were performed at Alfa Laval in Tumba, and was done by employees at Alfa Laval with different roles and with varying prior knowledge of the separator and the troubleshooting process of these separators. The tests were carried out individually and they took 15 minutes to perform. Each test began with the first questionnaire, which focused on the testers level of expertise. Following this, the testers were given a short introduction to the application. They also received the test tasks and were told to think aloud during the test so that their thoughts could be observed

and written down. During the test, the completion of each task needed to be approved by the test leader before the user could move on to the next part. After all the tasks had been completed, the second questionnaire was given, followed by six interview questions to engender some more detailed answers.

CHAPTER 5

Design and Development

In the following chapter the development process of the AR application will be described. The application was developed in four main iterations. Each iteration was divided into four parts, ideation, prototyping, user test and observation. The ideation focused on the new ideas for the functionality of the application, this could be from a previous iteration's user test or from other sources. The prototyping focused on the implementation of these ideas. The user test focused on testing these ideas and the observation focused on the takeaways from the tests. The same methodology was used for each iteration, except for the last iteration which included a larger user test, the results of this user test can be found in chapter 6.

5.1 Iteration 1

In Iteration 1 the goal was to figure out the conceptual design of the application as well as creating an initial prototype for both the AR part of the application as well as the non-diegetic UI.

5.1.1 Ideation

Based on information from the project's literature study, previous knowledge and the initial part of the design sprint, work began on establishing the different layers of the application's UI.

Camera view Designing an AR application for a smartphone means that screen space needs to be prioritized to the camera view to be able to show

the user as much as possible of the augmented world. Aside from the virtual objects that will be rendered in this view, all the user sees is a digital image of the real world. This means that the untouched camera view is the *diegetic* part of the UI. Everything rendered on top of the camera view is considered to be a part of the *non-diegetic UI* and all 3D objects rendered on top are a part of the *non-diegetic spatial UI*.

Non-diegtic UI   To create a first concept of the non-diegetic UI a storyboard was drawn to come up with different ideas on how to handle the alarms and how the overall user experience should be. The aim was to create a non invasive UI that should not grab too much attention from the AR camera view, which contains the most important information.

An idea that quickly arose was to create a UI that could exist both in a collapsed mode and in an expanded mode. Having both options gives the user a choice to either get a better overview of the alarms and the instructions, or collapse the view to allow more focus to be on the augmented world. After scanning the image and connecting to the PLC the user will be presented with all the active alarms, which can be seen in Figure 5.1. After an alarm has been chosen, the camera view with the augmented world is shown on the screen, as can be seen in Figure 5.2.

At the bottom of the screen the non-diegetic UI menu is in its collapsed state. Now the user can either start troubleshooting the alarm by pressing *begin process* found in the menu, or if they want to have a better overview over the instruction sequence they could expand the menu, as can be seen in Figure 5.3. To complete an instruction in the instruction sequence the user has to press a button to finish the instruction (see Figure 5.4), and when all instructions have been completed the user can acknowledge the alarm by pressing the *acknowledge* button as can be seen in Figure 5.5).
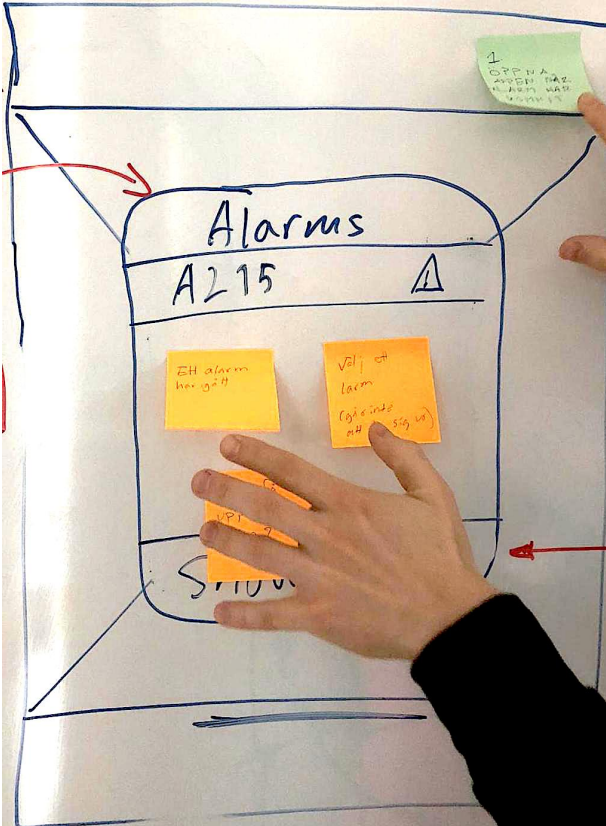
Figure 5.1: The list of all active alarms in a popup menu.
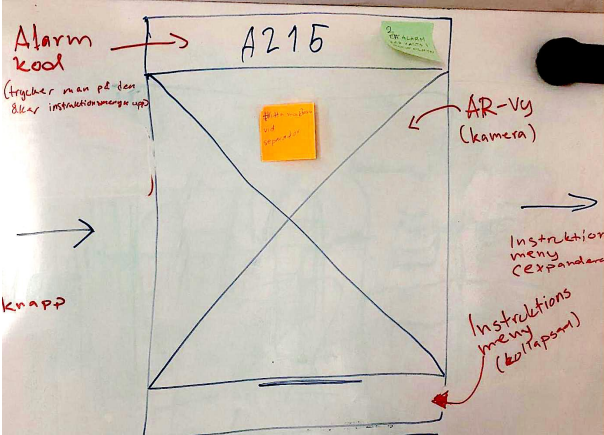
Figure 5.2: An alarm has been chosen, and the augmented world is shown through the camera.
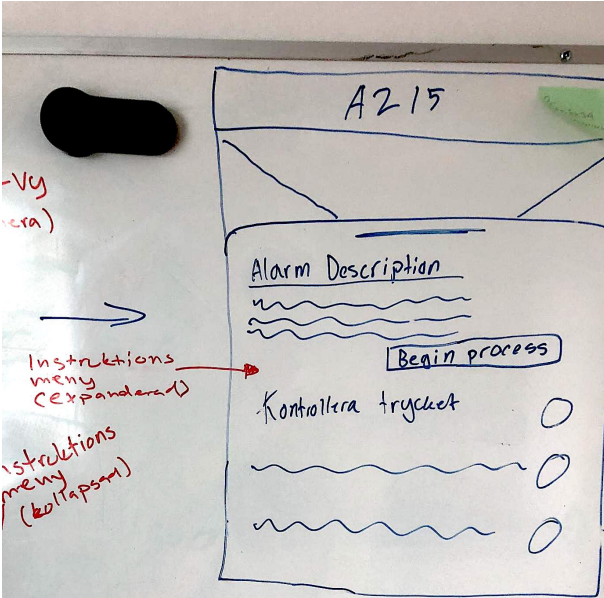
Figure 5.3: The instructions menu is expanded in this screen, and a button to begin the process is shown as well as step by step instructions.
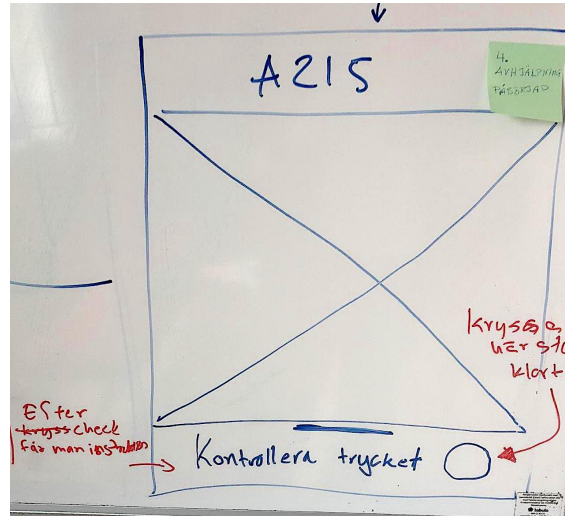
Figure 5.4: The process is now in progress and the current instruction step is shown in the instruction menu which is currently collapsed.
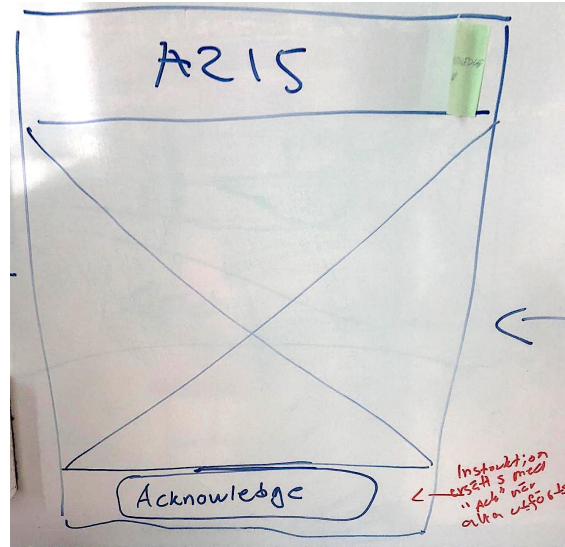
Figure 5.5: All instructions are completed.

Augmented Reality exploration   The first thing that needed to be addressed regarding the non-diegetic spatial UI was figuring out how to catch the user's attention both quickly and correctly. Ideas of using colors, shifting colors, animations and pointers to highlight where the components are located. These would be applied on virtual 3D models of the physical components rendered in the camera view on top of their physical counterparts creating an Augmented Reality. The idea here was to spatially map the virtual component to the physical component as closely as possible to take advantage of the spatial properties of AR.

5.1.2   Prototyping

Based on the storyboard of the non-diegetic UI a Mid-Fi prototype was created. The list of alarms was modified from a popup menu to the collapsible/expandable idea that was used for the instruction sequences, as can be seen in Figure 5.6. The begin checkup functionality stayed more or less the same as in the storyboard, with the addition of an exit button to return to the list of active alarms, which is illustrated in Figure 5.7. The instruction sequence with the expand/collapse feature stayed the same, which can be seen in Figure 5.8. When all the instructions have been completed, a done button is shown. This button is now green and can be seen in Figure 5.9.
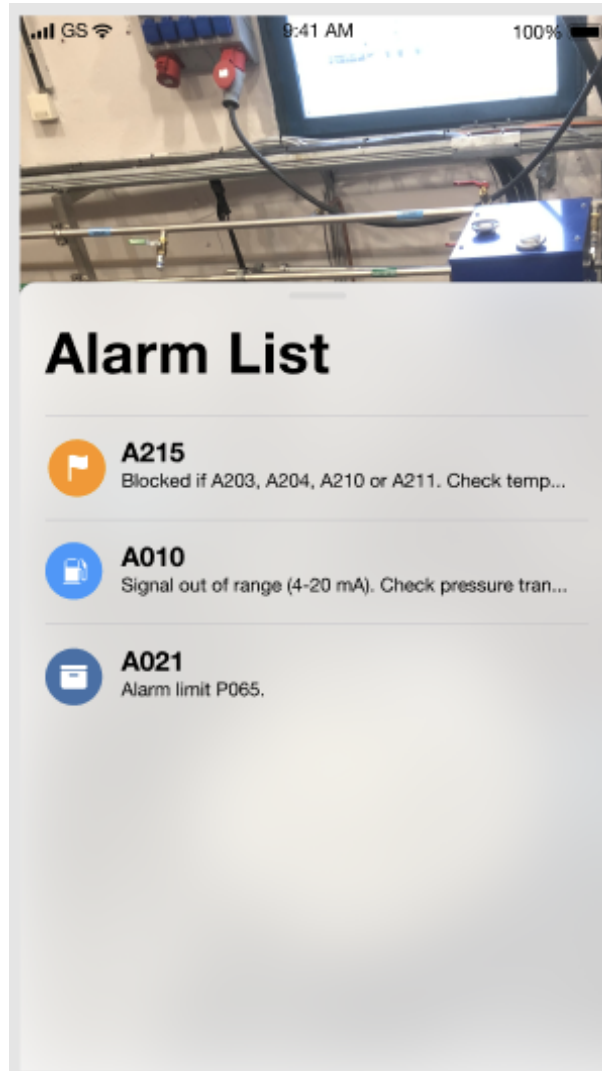
Figure 5.6: The list containing the active alarms. This list became a part of the collapsible/expandable instructions menu instead of being a separate popup menu.
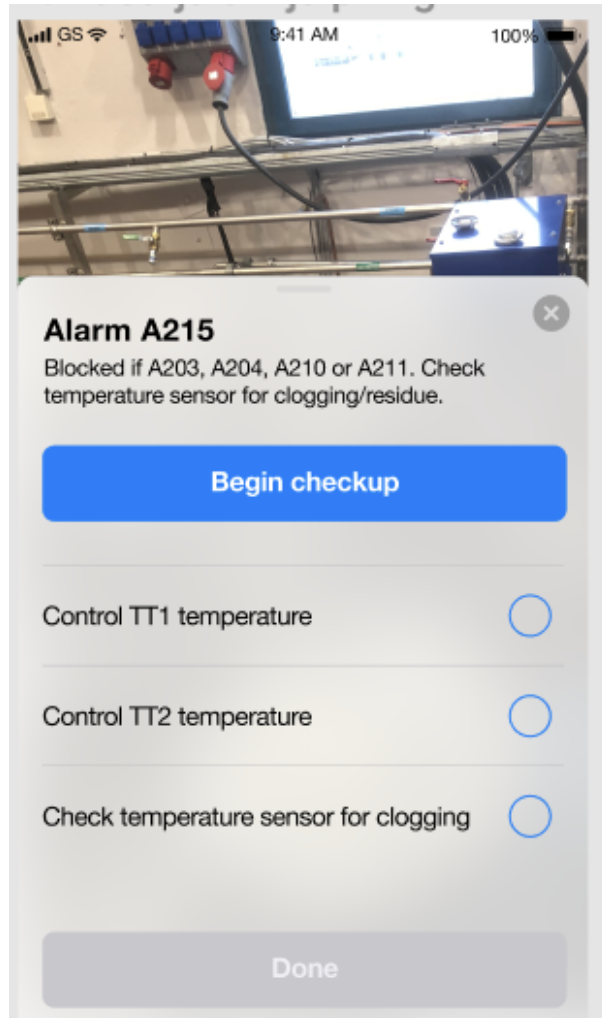
Figure 5.7: A begin checkup button and step by step instructions for solving the problems causing the alarm.
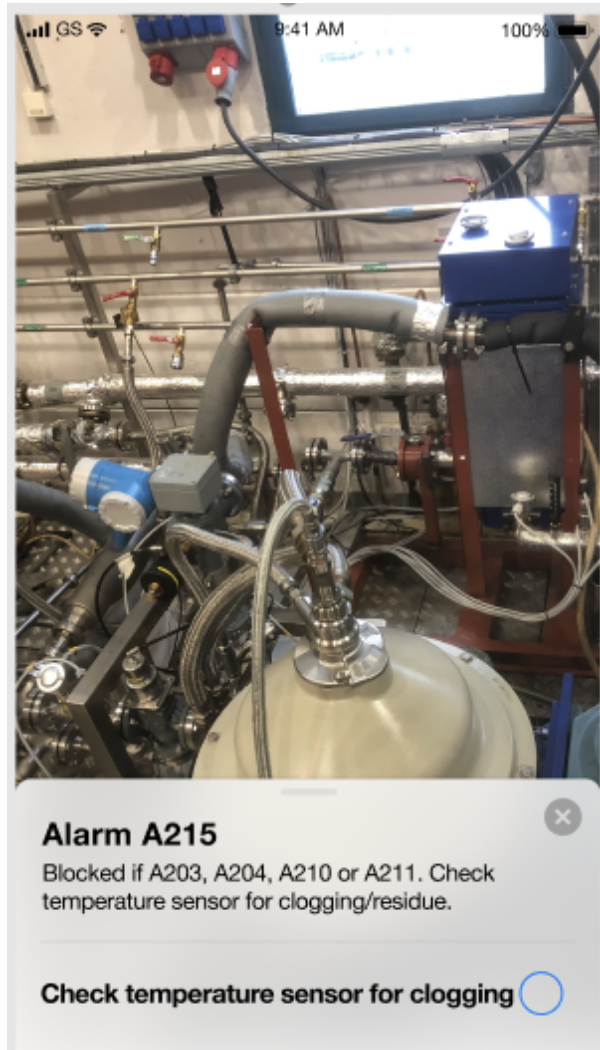
Figure 5.8: An instruction shown in its collapsed state.
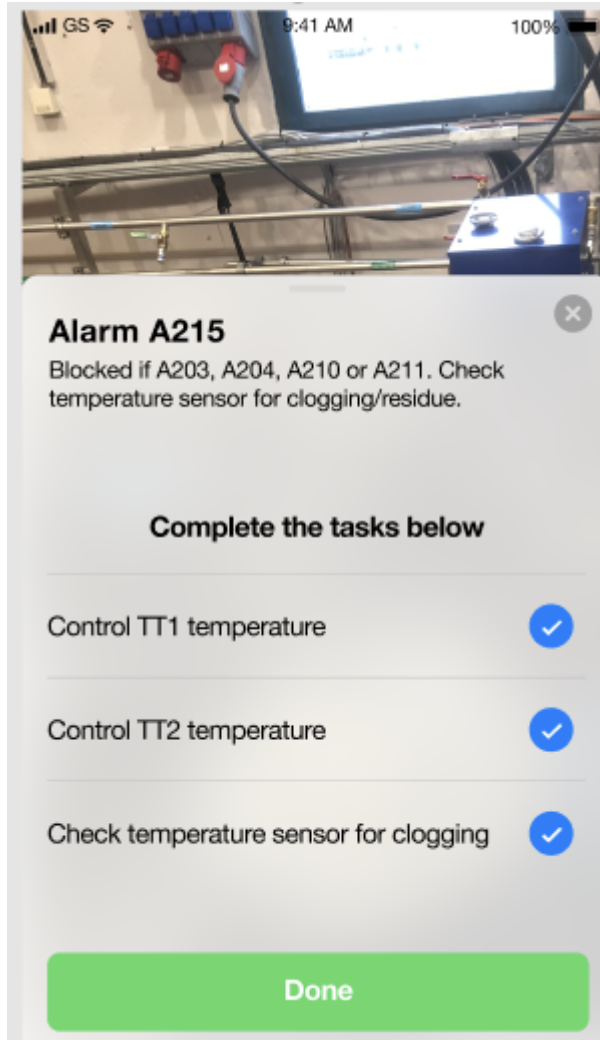
Figure 5.9: All instructions are completed in the expanded state.

Augmented Reality   The first prototype contained 8 different concepts that highlighted or pointed out a specific component:

- *Blinking*: A simple sequence where the specified component changes color between red and yellow to create a blinking effect.

- *Shaking*: The specified component is rotated in a such a manner that it emulates a shaking motion.

- *Breathing*: The specified component's size is increased and decreased in such a manner that it emulates a calm breathing motion.

- *Up/Down animation*: The specified component is moved up and down.

- *Text box*: A text box is shown above the specified component giving a description related to the alarm.

- *Particle system*: The specified component is highlighted with emerging particles that are animated with various sizes and speeds to create a sort of bubbling effect.

- *Static pointer*: The specified component is highlighted with the help of a static pointer above it.

- *Animated pointer*: The specified component is highlighted with the help of an animated pointer that is both rotating and moving up and down above the component.

PLC communication   To gather knowledge of how the PLC worked and how to create the necessary software to get information from the PLC to the prototype, two days were spent at B&R to gain a basic understanding of how of their system works. During these two days, a TCP server was developed as well as a simple web interface that could generate real alarms. The TCP functionality of the server was kept simple, and the idea was that a smartphone would connect to the server via a wireless network. After a connection is established, the server will send a bitstream of an array containing the current active alarms. The AR application receives the bitstream and converts it to a list of alarms which is displayed.

5.1.3   User tests

A smaller user test was conducted to receive some much needed feedback regarding the different concepts. Five testers, who were employees at Jayway, without any prior knowledge of the separator were selected. The AR

concepts were tested on the five users who were given no instructions before starting the test. The testers were shown all the eight concepts and for each concept they were instructed to think aloud and express their initial impressions, as well as to explain what they thought they were supposed to do when a specific concept was shown. Each tester's thoughts were noted and observed. The results of the test gave a lot of answers and showed that some of the concepts were perhaps flawed from the beginning, at least for its intended use. The main takeaways from the user test are listed below.

5.1.4   Observation

Takeaway 1   When animating the actual component almost all the users immediately thought that they were supposed to interact with the component in some way, when the intention was simply to catch the their attention.

Takeaway 2   The use of animations that are physically possible like rotation and moving the components in 3D space was overall preferred over animations that are changing the components in unnatural ways. For example, changing the size of the component was more confusing than rotating the component.

Takeaway 3   Perhaps the most important takeaway was how all the users felt that using combinations of the different concepts would create even more effective highlights of components. For example, combining the text box with the animated pointer or using the blinking animation together with one of the other animations could create an even better experience.

Additional thoughts   Separating text containing instructions and other information from the augmented world creates a need of connecting the non-diegetic spatial UI and the non-diegetic UI. This is a quite challenging task as the non-diegetic UI lacks the three dimensional spatial information that can be determined from the non-diegetic spatial UI in the augmented world.

5.2 Iteration 2

In the second iteration the goal was to merge the two prototypes created in the first iteration. This meant that the Mid-Fi prototype that was created for the non-diegetic UI needed to be integrated with the AR functionalities into one cohesive application.

5.2.1 Ideation

First of all, how the workflow would function was discussed, from scanning an image to see if a separator currently has any active alarms, to dealing with the active alarms and troubleshooting them. The main functionality inside the application is in the non-diegetic spatial UI in the AR camera view and therefore it should always be at the center of attention. All the non-diegetic UI elements should take up as little screen space as possible. This spawned the main idea with the non-diegetic UI in the first iteration, which utilized a card containing the alarms and their instruction sequences. This card could be collapsed into a smaller view but also work in an expanded state to provide a better overview over all the active alarms or all the instructions for a specific alarm. Now the big question was: when should the menu be expanded and when should it be collapsed for the best user experience?

When merging the two parts together it became obvious that the application needed to work in a more linear fashion than anticipated. The different instructions that are displayed for a specific alarm needs to be performed in the same order each time. This is because each instruction highlights a different component of the separator and you can't highlight multiple components at the same time without causing confusion for the user.

Pointer In the first iteration the focus was on how to highlight components when the users looked at them and this meant that no thought was put into how to highlight components when they weren't visible on the screen. This meant that the users had nothing that guided them when they weren't already looking in the right direction. To move the user in the right direction, there was a need for some kind of pointer or highlight that wasn't directly placed on the component, since it had to be visible on the screen even when the component wasn't visible. With this in mind, the idea of an arrow pointing in the direction of the component was born. The arrow would be placed at the edge of the screen when the component wasn't shown, providing a sense of direction to the user, allowing them to see in which direction they should move the phone in order to find the

component. For the user to easier understand what the arrow points at, other than looking at the direction of the arrow, there needed to be something more that connected or gave the arrow and the component a sense of being part of the same group. An idea to achieve this, based on the gestalt principle of similarity, was to use the same colors on the arrow as on the component it was pointing at. Additionally, the movement of the arrow and the movement of the component off screen would adhere to the gestalt principle of common fate, even though the component couldn't be seen.

Figure 5.10: 2D pointer.

Initially, the idea was to have a 2D arrow, as can be seen in Figure 5.10, moving across the screen telling the user if they should move the device up, down, left or right. This idea was scrapped and replaced with the concept of a 3D pointer that would feel more like a part of the augmented world,

since it was a part of the non-diegetic spatial UI, and would be able to point in 3D space instead of only in 2D space. The user's movement of the smartphone was also mapped directly to the direction of the 3D pointer, complying with Norman's design principle of mapping.

Text box One key takeaway from the user test in the previous iteration was that animating a component's size and position afforded that the user should perform some sort of interaction with the component, like unscrewing it or removing it. These kinds of animations could be useful later in the project, but at this time the most important thing was to direct the user's attention to the correct component. Considering this, the highlight with the most potential from the initial tests was the *blinking*. Furthermore, the test showed that a combination of different types of highlighting made it more evident which component wanted their attention. Apart from the two pointer highlights, the text box was the only other highlight that didn't animate the component's size or position, so it would be possible to combine a text box with blinking to increase the highlight's efficacy. The reason why the two pointer highlights were ignored at this time was because the other pointer mentioned earlier was thought of as having a similar effect in guiding the user. Moreover, having both a text box and a pointer with close proximity to each other could be perceived as cluttered to the user.

Instruction component feedback The major task of this iteration was to connect the non-diegetic UI with the non-diegetic spatial UI of the augmented world and make the prototype feel like one coherent application. Since the non-diegetic UI showed the instructions and the components were highlighted in the augmented world, there was a call for some kind of feedback in the augmented world when an instruction was marked as done in the non-diegetic UI. According to research, the color green can evoke multiple positive emotions, like calmness and comfort, and would therefore be a suitable color to use on a component after the instruction is marked as done.[27] Coloring a component green after its related instruction is completed would first provide feedback to the user that the instruction was completed and later give the user traceability from the visual representation of which components that have been checked.

5.2.2 Prototyping

A working version of the non-diegetic UI was created within the application that contained the main concepts of the Mid-Fi prototype but with some alterations so it could work from a technical standpoint.

Figure 5.11: List of alarms.

The application opens with a camera view and an instruction telling the user to scan the QR code. Scanning the QR code will bring up a card showing a list of all the currently active alarms on the separator, as can be seen in Figure 5.11. Above the list of active alarms is a title and a number showing how many alarms are active. This card can be dragged to either a collapsed view or an expanded view, as can be seen in Figure 5.12.
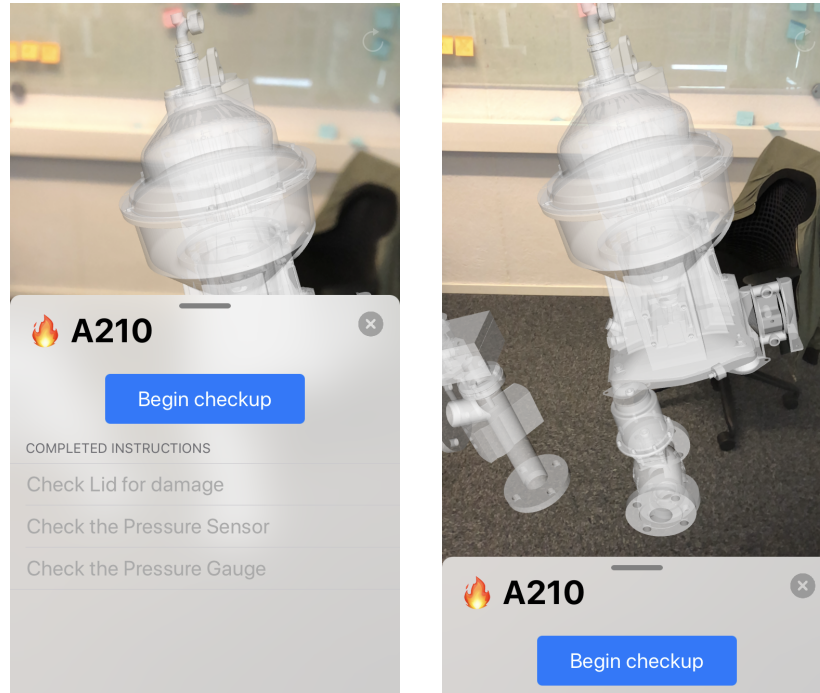
Figure 5.12: Begin checkup in collapsed and expanded state.

It's possible to perform all instructions in both the collapsed and expanded state, where both have their advantages. If the user needs an overview over what instructions that have been performed, then the expanded state is preferred, but when the user wants to locate a specific component the collapsed state gives more space to the camera view.
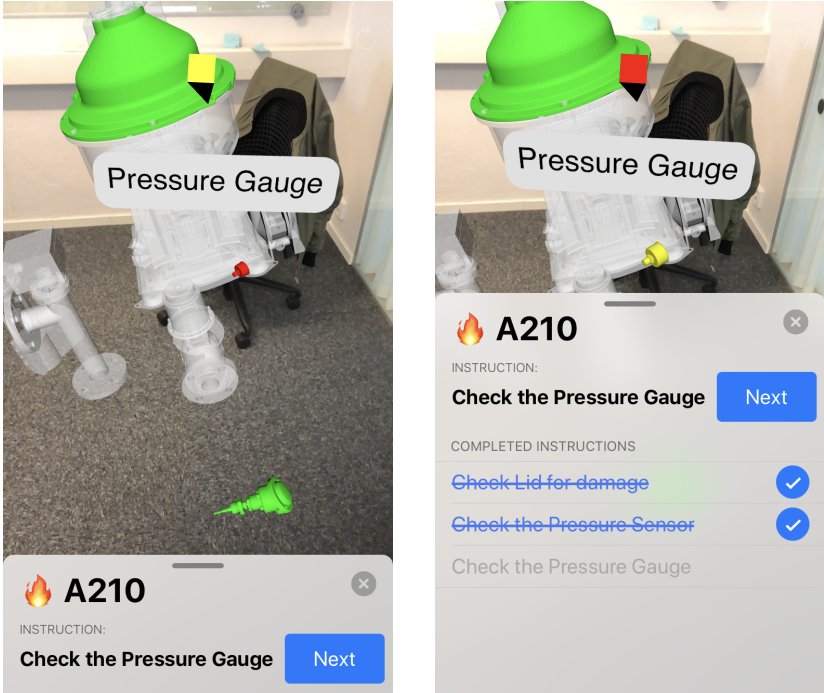
Figure 5.13: Next instruction in collapsed and expanded state.

As can be seen in Figure 5.13, the expanded state of the instruction menu provides a clear overview over which instructions that have been carried out, and with the combination of the feedback provided with AR it should be easy to understand what has been done and what still needs to be performed in order to finish the troubleshooting.

Figure 5.14: All instructions done in collapsed and expanded state.

As can be seen in Figure 5.14, you can't press the done button when you are in the collapsed state of the instruction menu. This is because the user should be encouraged to check the instructions one more time and make sure that each step as been performed. Hopefully this reduces the chance that an alarm is handled in a faulty manner.

The augmented world now contains more components from the separator system than before. When an alarm instruction sequence is initiated, the component associated with the first instruction starts blinking in red and yellow and a text box is placed above it displaying the component's name. When the user presses the next button in the non-diegetic UI, the previously blinking component is colored green and the text box moves to the component associated with the next instruction. This is repeated until all instructions are completed and the user presses the done button in the non-diegetic UI and thus hides all the components highlighted during the sequence.

At the top of the screen, there is a 3D pointer that points toward the

currently blinking component. The pointer is also blinking in the same colors as the component. Even though the pointer exists in the augmented world, its position is locked to a few centimeters in front of the smartphone's camera and is therefore always visible to the user, as can be seen in Figure 5.13.

5.2.3   User tests

In the end of the iteration a user test was conducted to test how well the non-diegetic spatial UI in the augmented world worked, how the non-diegetic UI worked and how well they worked as a cohesive application. Similar to the test in the first iteration, a virtual separator was used, as well as simplified versions of real alarm instructions. The instructions during this test focused on the *discoverability* of different components. Five testers, who were employees at Jayway, without any previous knowledge of the separator were selected. The test was performed by the five users who were given a short written instruction. During the test the users got to troubleshoot three different alarms with three instructions each. The instructions were kept simple and easy to perform and during the test users were told to explain how they perceived the different functionalities within the application and whether or not these functions were good and/or easy to understand in their current format. Each of the testers' thoughts were noted and observed. The test provided a lot of valuable thoughts regarding the new functionalities that has been added during this iteration as well as more feedback on the overall application and how it works. The results of the tests are summarized in a few key takeaways in the next section.

5.2.4   Observation

Takeaway 1   All the users felt like the pointer was very helpful to locate components that were not visible in the AR camera view. The users felt like they were guided in the right direction in a non intrusive manner. However, some adjustments could be made to the pointer to make it even better. Some users felt a bit confused by the pointer when the correct component was visible in the AR camera view. One example was that a user did not fully understand why the pointer continued to blink in red and yellow like even when they saw the correct component on the screen and therefore thought they were doing something wrong. Perhaps the pointer should provide some kind of feedback to indicate when the user is looking at the correct component.

Takeaway 2   The text box provides some assistance for figuring out where a component is, especially when the users need to shift their attention to a new component. This animation is more effective when the user stands a couple of meters away from the component, since the distance allows them to see the entire animation of the text box's position. If the user stands close to the component, the text box will move out of the screen almost immediately and the effect of the animation is lost.

Takeaway 3   Without previous knowledge, it's not obvious to the user that it's possible to drag the bottom cards between the expanded and collapsed states. Using an arrow-shaped icon to indicate this could be a stronger signifier and increase the affordance to the user that they can move the bottom card up and down to see more or less of the augmented world.

Additional thoughts   If the user accidentally proceeds to the next instruction or for some other reason wants to go back to the previous one, how could that functionality be implemented? When all alarms on a separator have been dealt with, what should be displayed to the user?

5.3   Iteration 3

The third iteration focused mainly on polishing the application created in the previous iteration. This meant finding and resolving all the bugs that were found during testing as well as modifying the application based on the feedback that was received during the user tests in Iteration 2.

5.3.1   Ideation

Blinking   Based on the user tests and observations in Iteration 2 the usage of blinking components seemed to be overwhelming and may perhaps have a negative effect compared to using one solid color.

Instruction sequence navigation   An important functionality that had been lacking in the previous versions of the application was the possibility to uncheck and return to a previous instruction. Allowing the user to undo an action is important and can improve the experience greatly. It was discussed how this functionality should be implemented. Can the user return to any instruction in the alarm, or perhaps the solution should be to use a previous button that worked similar to the next button already existing in the application? The issue with a previous button is that the user can only go to the previous instruction when in reality, the desired instruction may be five instructions back.

In the end it was agreed that it would create a better user experience if the user is able to return to a specific instruction directly and not returning step by step. However, some instructions might rely on an earlier instruction, so by returning to a instruction four steps back, the user has to redo all of the four steps.

The application also lacked a complete sequence, mostly missing a clear end. In the earlier versions of the application an alarm was never removed from the alarm list after it was finished, this meant it was not completely clear to the user if they had finished troubleshooting a specific alarm. To clarify when an alarm has been acknowledged and cleared, it should be removed from the alarm list, and when all alarms had been taken care of, the alarm list card could be dismissed and the application goes back to its initial state.

Alarms   During this iteration, another visit to the lab at Alfa Laval in Tumba was made. This meant that employees from Alfa Laval were avail-

able for consultation during the ideation. Working closely with them, the idea of overhauling the alarms used in the application emerged.

AR animations   Based on the feedback from the user tests in the previous iteration, the users seem to be able to find the components quite easily. This sparked the idea to bring back animations to the components, providing visual guidance in addition to the instruction text.

5.3.2   Prototyping

Dragging functionality of the non-diegetic cards   During the tests in the last iteration a lot of users didn't seem to understand the expanding and collapsing functionality of the alarm and alarm list cards. When the users were asked if they had understood the possibility of expanding and collapsing the card by dragging the it, most hadn't found this functionality naturally. This meant that the icon that indicated the dragging functionality did not afford this possibility. This icon was improved by, instead of it being a narrow rectangle, it was changed to an arrow pointing either downwards, when in the expanded state, or upwards, when in the collapsed state. This change should improve the discoverability of this functionality by signifying the function of dragging up or down. The implementation of the arrow can be seen in Figure 5.15.
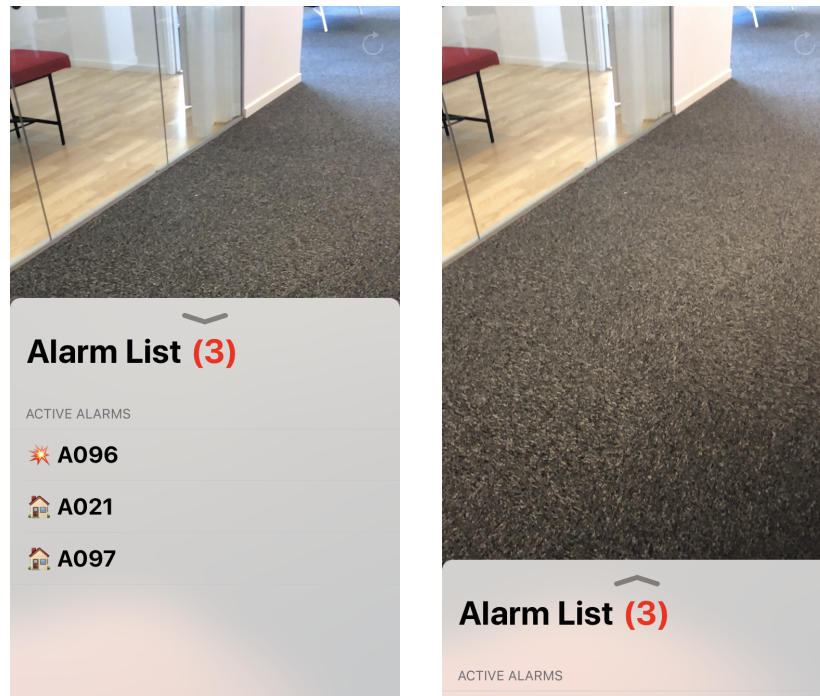
Figure 5.15: New arrow icon to indicate the dragging functionality.

Instruction sequence navigation   The possibility to undo completed instructions and returning to an earlier point in the sequence was added to the application. When an instruction is completed, a checkmark is filled to indicate that the instruction has been completed. By simply unchecking the checkmark for the desired instruction the user wants to return to, the application is reverted to the exact same state that it had at that point in time. This means that all instructions between the two points are also unchecked, essentially all progress made is reverted to the desired instruction and has to be redone. This way of handling the undoing of instructions was chosen mostly because some instructions rely on previous instructions being fulfilled. Instead of redoing some instructions, some of which may not be needed to be redone, the user can easily traverse through the instructions back to the last instruction that they had completed before going back.

The application also needed to have a more concrete end-point. This was

achieved by removing alarms from the alarm list when an alarm had been completed. When all alarms in the alarm list had been troubleshot, the text would be changed to green to indicate a successful troubleshooting as well as the possibility to discard the alarm list card. When this card is discarded and the application is back to it original state, a new scan of the image can be performed. This can be seen in Figure 5.16.
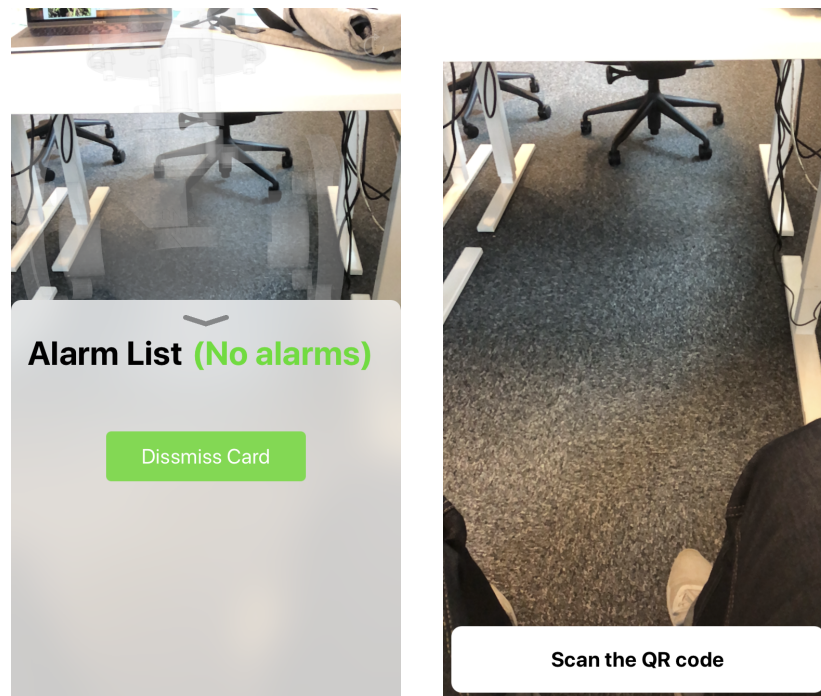
Figure 5.16: Dismiss card functionality when all alarms have been troubleshot.

Alarms   The alarms used in the application were changed to three alarms triggered by mechanical problems.

AR animation   Now that the alarms involved more mechanical parts, instructive animations were added to some components. These are supposed to complement the instruction texts. The two animations that are used are rotation and movement in one direction. Rotation is used when the

instruction suggests that the user should unscrew a component or check if a component can be rotated. The move animation is used when the user is instructed to remove a component.

Mapping the components   The components in AR were mapped to their physical counterparts on the separator.

5.3.3   User tests

The user tests were performed with the physical separator in the lab at Alfa Laval in Tumba. This test was performed by seven employees at Alfa Laval. The employees had different levels of experience of the troubleshooting process and the separator. During the test, each participant could explore the application however they wanted. The only exception was that the scanning of the image to set up the tracking and mapping was done before they got the smartphone. Each of the seven testers had three alarms available in the application that they could troubleshoot. The testers were instructed to think aloud and disclose all thoughts they had regarding the application. These statements and thoughts were written down. Additionally, the behaviors and decisions of the testers were monitored. The results of the tests are summarized in a few key takeaways in the subsequent section.

5.3.4   Observation

Takeaway 1   The users only get a limited understanding of the pointer if they remain still while using the application. If the phone doesn't move, then the pointer doesn't move (apart from when they click next and then it points to another component) and this often results in the users not realizing that the pointer is there to help them find the components.

Takeaway 2   The application is having a lot of issues with AR tracking in the environment around the separator. This is most likely because the AR tracking has a hard time finding horizontal planes and their feature points. This leads to a situation where the AR tracking is not stable, and currently the application needs to be stabilized by scanning the image repeatedly to readjust the augmented world.

Takeaway 3   While performing the tests at the lab in Tumba it was brought up that the troubleshooting sequence can find the actual problem causing the alarm at different points of the sequence. Sometimes the

first instruction of the troubleshooting might be the cause of the problem, and this means the rest of the instructions won't be needed to be performed. This also meant that, in some situations, the troubleshooting might not find the cause of the problem. In those situations the cause of actions would be to contact Alfa Laval to get further assistance from a well trained service technician. This interaction is something that should be a functionality within this application.

5.4   Iteration 4

In this iteration, the focus was on the functionality for when the user needs more help than the instructions provided in the application, fixing bugs and preparing for the final user tests. The feedback from the previous iteration was taken into account and was used as a starting point for the ideation.

5.4.1   Ideation

The key takeaway from the last iteration was that the user might not have solved the problem with the separator with the instructions provided in the application. Whenever the problem causing the alarm is this complex, the user needs professional help from Alfa Laval. To aid the user in a situation like this, a button with additional information could be useful.

5.4.2   Prototyping

Only one new function was added to the final prototype: a button that provided the phone number to Alfa Laval's support. The button is placed to the left of the "Done"-button and has a label that says "More help?" (Figure 5.17). Pressing the button opens a modal with the phone number and a "Call"-button that starts a call to the same number (Figure 5.17).
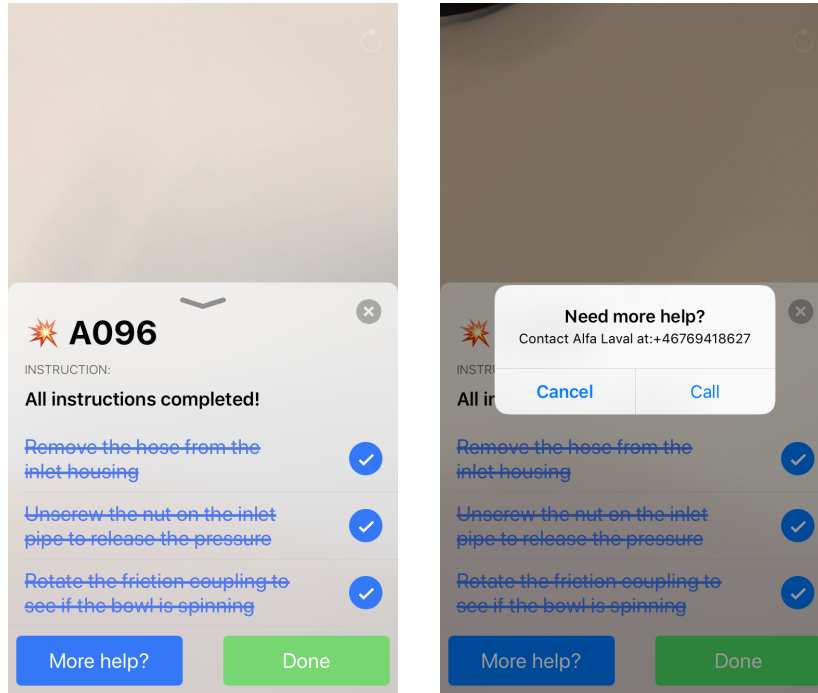
Figure 5.17: More help functionality, with contact information.

To improve the AR tracking, and especially the initial mapping, a larger
and more detailed image was used for the image recognition scanning that
is performed when you open the application.

The TCP server that was created in Iteration 1 to retrieve alarms from the
PLC was also integrated into the final application. The TCP server needed
some minor modifications to run on the PLC correctly, and a wireless net-
work was also connected to the PLC, making it possible to connect to it
from the smartphone.

5.4.3   The final application

After the prototyping phase in Iteration 4, the development was concluded
och no more functionality was added. This was the final application that
was used in the user tests described in Chapter 6. In the final application
the functionalities were:

- Scanning the image to retrieve the active alarms and mapping the augmented world correctly.

- See the list of active alarms on the *alarm list card*, as illustrated in Figure 5.11.

- Select an alarm and see the instructions for the specific alarm on the *alarm card*, as seen in Figure 5.13.

- Highlighting of the AR component related to each instruction. This is illustrated in Figure 5.18

- Animated components to complement some instructions.

- An AR pointer that guides the user in the right direction, as can be seen in Figure 5.18.
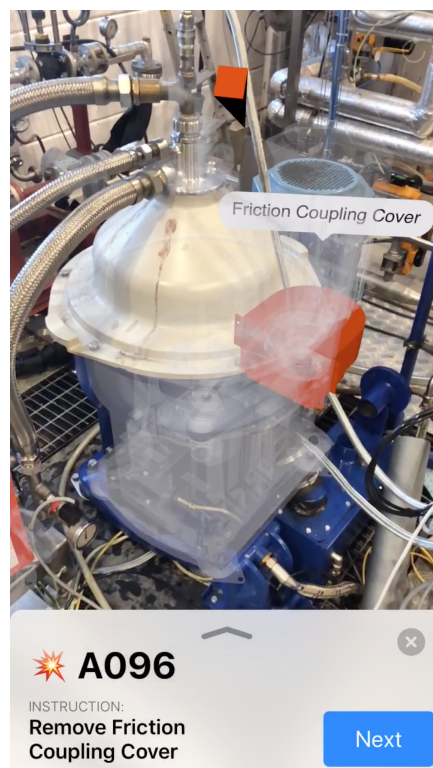
Figure 5.18: An instruction with a highlighted component in the final application.

CHAPTER 6

Verification

The following section will present the result of this project based on the verification phase, described in chapter 4.

6.1 User test

User tests of *the final application* (from Section 5.4.3) were conducted with eleven participants with different backgrounds and knowledge.

The test participants had one major task during the test: troubleshoot all the alarms in the alarm list. Each alarm had a set of instructions that the tester was to perform. Since some instructions included removing or disassembling parts of the separator, they only needed to say out loud what they would have done with the component instead of actually doing it. The tester couldn't move on to the next instruction before they had been cleared to do so by the test leader.

6.1.1 Initial questionnaire

Before testing the application, each tester first had to answer four questions about themselves. The first question was "How old are you?" and the result is shown in Figure 6.1. In Figure 6.2, the result from the question "How familiar are you with the troubleshooting process?" is presented. The third question was "How familiar are you with the separator?" and the result can be seen in Figure 6.3. In Figure 6.4, the result of the question "Have you used Augmented Reality before?" is presented.

How old are you?

11 svar
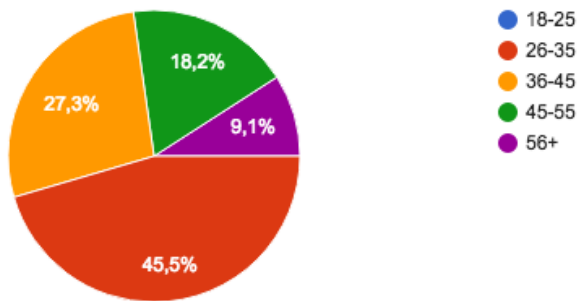
Figure 6.1: The distribution of the answers to the question "How old are you?"

How familiar are you with the troubleshooting process?

11 svar
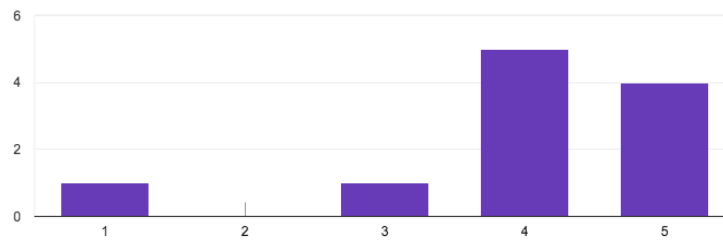
Figure 6.2: The distribution of the answers to the question "How familiar are you with the troubleshooting process?" where 1 is "No prior knowledge" and 5 is "Expert knowledge"

How familiar are you with the separator?

11 svar
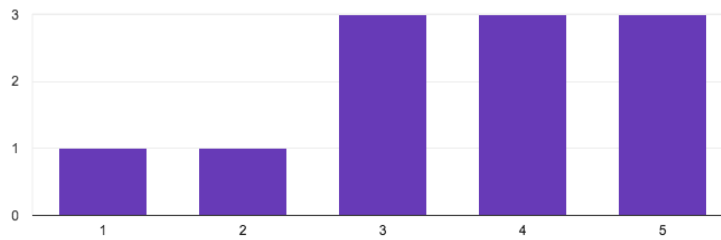
Figure 6.3: The distribution of the answers to the question "How familiar are you with the separator?" where 1 is "No prior knowledge" and 5 is "Expert knowledge"

Have you used Augmented Reality before?

11 svar
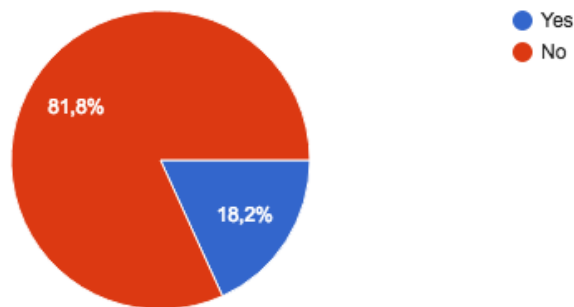
Figure 6.4: The distribution of the answers to the question "Have you used Augmented Reality before?"

6.1.2   Questionnaire after the test

After the test, each tester answered a questionnaire with four questions related to the test and their experience during it. The first question was "How confident are you of performing a troubleshooting after this test?" and the

result can be seen in Figure 6.5. This question is related to, and should be compared with, the result in Figure 6.2 ("How familiar are you with the troubleshooting process?"). In Figure 6.6. the result of the question "How helpful do you think this kind of solution can be for troubleshooting alarms?" is presented. The result of the question "Could you see this kind of solution being used to reduce the workload for well trained service technicians?" is presented in Figure 6.7. The final question was "Could you see this kind of solution being used during the training process of new service technicians?" and the result can be seen in Figure 6.8.
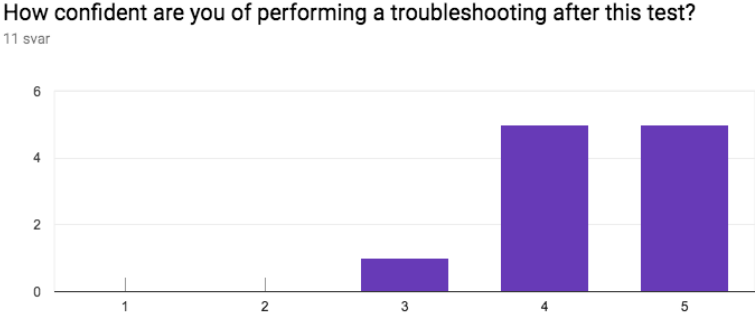
Figure 6.5: The distribution of the answers to the question "How confident are you of performing a troubleshooting after this test?" where 1 is "Not confident" and 5 is "Very confident"

How helpful do you think this kind of solution can be for troubleshooting alarms?

11 svar
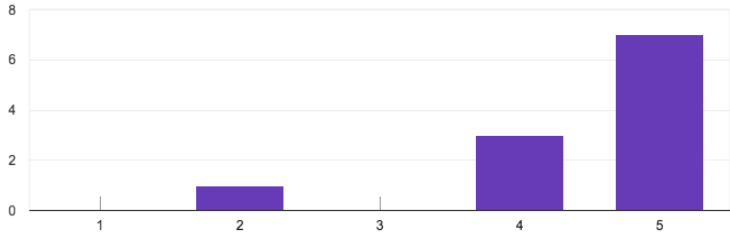
Figure 6.6: The distribution of the answers to the question "How helpful do you think this kind of solution can be for troubleshooting alarms?" where 1 is "Not helpful" and 5 is "Very helpful"

Could you see this kind of solution being used to reduce the workload for well trained service technicians?

11 svar
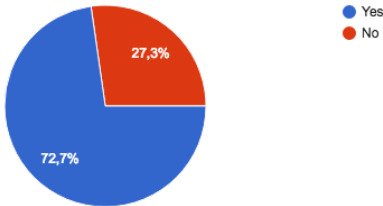
Figure 6.7: The distribution of the answers to the question "Could you see this kind of solution being used to reduce the workload for well trained service technicians?"
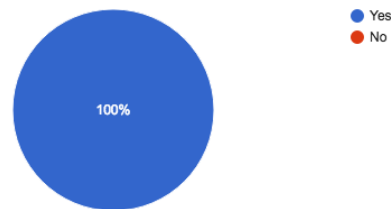
Figure 6.8: The distribution of the answers to the question "Could you see this kind of solution being used during the training process of new service technicians?"

6.1.3   Tester feedback during the test

During the test the testers were urged to "think aloud", i.e. give feedback whenever they wanted. The testers' most notable thoughts were written down and the most prominent ones are presented below:

"More data could be sent to the phone from the PLC which would mean that you don't always have to be close to the separator."

"Messages next to the alarm code would be helpful, especially if you are experienced with the machine, you learn some specific alarms that are frequent."

"The animations work good to help the instruction, more alarm information should be in the application."

"This application is too simple for expert service technicians, but can be used for teaching."

The complete set of thoughts from the testers can be found in appendix B.

6.1.4   Observations

In addition to writing down the testers' thoughts, observations of the testers' behaviors were made and written down. The complete set of observations can be found in appendix B.

The most recurring observation was that the testers tended to stand still and not move around in the limited free space around the separator. This resulted in the pointer not moving and a misunderstanding of how the pointer worked. One tester thought that the pointer pointed straight down when in reality it pointed down and back. Three of the testers had used the application in a previous iteration and they used the pointer more than the testers that had not used the application before.

Another repeating behavior was that testers just clicked next after reading the instruction without actually finding the component.

6.1.5 Interview questions

The last part of the test consisted of interviews with the testers. They were asked six questions, all of which will be presented below with the most notable answers:

Question 1. How was the experience of finding the first component with AR?

"Pretty easy, but the screen is too small, which makes the Field of View too small."

"A blinking animation could improve the experience."

"The pointer helps to find the component."

Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?

"Yes it's a good idea, it would be good to have perhaps even more detailed animations."

"The animations look good, they show what the instructions say. The use of color showing already checked components in green is easy to understand. Simple, but effective and you can build upon it to show more complex animations."

Q3. Was the pointer helpful when finding the components?

"The pointer is helpful, especially if you don't know the components."

"No, might be need more effects, like more colors or shadows, to make it better."

"It's good. Use shadows to make the 3D-stand out more."

"The pointer might improve with another shape or if it's blinking."

Q4. Was the text box floating above the components helpful when finding the components?

"It might not be the best, it can cover the screen."

"The text box is very helpful to find the components, could also be helpful to find specific components even when no alarms are present."

"The text box is nice when finding the correct position and helps with the naming."

"Could be risky in confined spaces since you sometimes need to move to see the entire text box."

Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?

"It might have helped, I did not notice it."

"Not really, but it could be useful."

"Perfect, it worked."

Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?

"More information in the application, so you don't have to use both the HMI and the application."

"Link spare parts to the application."

"More alarm information. The level of detail in the models."

The complete set of answers can be found in appendix B.

CHAPTER 7

Discussion

In this chapter the method used when developing the AR prototype, the results of the user test, difficulties and limitations, and future work is discussed.

7.1 The AR troubleshooting experience

For this master thesis the purpose was to explore if Augmented Reality could assist people without expert knowledge in the troubleshooting process of separator alarms. By looking at the results of the first question in the post-test questionnaire (Figure 6.5) it seems that people overall felt confident in troubleshooting the alarms that were used during the testing. In the second question of the post-test questionnaire (Figure 6.6) the result indicates that the usage of AR as a supporting tool for troubleshooting could become very helpful.

Another sub-question that was answered during the user tests was if this idea of using AR could reduce the workload for experts as well. Based on the results in the post-test questionnaire (Figure 6.7), it seems that people overall felt that this type of technology can reduce the workload for expert service technicians. However, during the testing it was observed that experts that tested the application more or less felt hindered by the application instead of assisted. Even though they can't benefit directly from using the application, one tester gave an interesting answer that might explain why the majority of the testers answered yes to the question in Figure 6.7. The tester said that if the application is being used by the correct user group, then they could troubleshoot the alarms and solve the

problems without needing to contact the experts for assistance. This would mean that the experts could focus on the more complicated issues instead of troubleshooting the easier alarms. So indirectly it might actually reduce the workload for experts as well.

The last question that was asked in the post-test questionnaire regarded education and whether or not this application could be used for educational purposes. As can be seen in Figure 6.8 it was unanimously agreed that this could be the case. This result highlights the biggest advantages of using AR. With AR you can visualize the different components that creates the separator, you can break it up to individual pieces and this could all be done without actually having a physical separator present. Using a digital representation of the physical separator the risk for breaking something is removed. The second advantage with AR is the combination of the real world and the virtual world. The ability to place a virtual object on top of its physical counterpart is unprecedented and allows for a direct mapping between the both worlds which cannot be done with any other technology.

During the testing a lot of aspects that might be overlooked by developers. The physical environment that the solution should be used in is something that can not be overlooked during the planning of the application. During the open ended interview questions one question was about the text box (question 4). One response was:

"Could be risky in confined spaces since you sometimes need to move to see the entire text box."

Because the separators are used in a plethora of locations and environments a discussion started about what kinds of environments could exist and how they could affect the application. A confined space limits the possibility to walk around the whole setup, which requires the user to see all digital components in the application without having to move around too much. As the tester said, you sometimes have to move to see the full text box, and if you take a step back in the wrong places there might be a pipe behind you that is scorching hot. The separator might also be located in an engine room on a boat, where the lighting is less than optimal. Furthermore, since the ARKit framework relies on the camera to create the augmented world, so if the conditions are less than optimal a lot of issues could occur.

7.2   Interaction design for AR

During the history of software design screens have been used as the pre-dominant medium to display the UI to the user. Constrained by the pixel grid on the screen, designers have consequently created interfaces with two dimensions. One exception is video game design, which often uses three dimensions, and it's one place to look for inspiration when designing for AR. The problem is that video games, traditionally at least, do not combine the real world with the virtual world. Designing with both real and virtual in mind is a new concept in software design that hasn't been around long enough to develop the kind of standard interactions that can be found in 2D software.

The purpose of this master thesis was to explore how AR could be used to help people with less knowledge of a separator to troubleshoot alarms. From an interaction design perspective this meant that the most crucial part of the application was to help the user find the correct component. To determine how to help the user find the correct component, one must understand the user. Thus, UCD was employed and since the end user was someone without knowledge of the troubleshooting process, the target group was virtually everyone. Testing the application after every iteration provided useful feedback, especially in the beginning of the project when attention seeking animations on the components were evaluated. User test also shone light on the keyhole effect of using AR with a small smartphone screen. Components that were located outside of the smartphone's field of view were difficult to discover before the implementation of the 3D pointer. Based on these insights and many more during the project, choosing to apply UCD can be seen as a great decision and a major contributor to the the look and functionality of the final application.

Working with AR on a smartphone also implies that the user will hold the gateway to the augmented world in their own hands. Using the application, the user interacts with the augmented world by both moving around in the real world, and thus moving in the augmented world, and by touching the screen on the smartphone. Hence, as when designing video games, designing for AR entails decisions about the diegetic, non-diegetic, meta and spatial parts of the UI. The diegetic part of the UI is the camera view and one could in fact argue that the real, physical components of the separator are also part of the diegetic UI. In accordance with Ronald T. Azuma's definition, AR combines real and virtual, so why couldn't the physical components be seen as a part of the UI? This is an area where the lines between real, virtual, machine and computer are blurred.

Naturally, the virtual components in the application are a part of the non-diegetic spatial UI as virtual 3D objects. This allows a direct mapping between physical component and virtual component, with the virtual component overlaying the physical one. This worked as an intuitive way for the users to find the physical component with help of highlighting from the virtual component. The decision to display the instructions and other text in the application as a part of the non-diegetic UI was an attempt to reduce the amount of novelty and make one part of the application familiar by designing it to look and feel native on the iOS platform that it was built for. Hopefully this eased the transition from traditional 2D applications to this AR application.

7.3   Difficulties and limitations

Over the course of the project there have been problems and hindrances. Most of the issues have revolved around AR and the ARKit framework, this is mostly due to the fact that it is such a new technology that has not been been perfected yet. A lack of experience working with the technology is also a reason. This meant that it was a learning process throughout the project. Most notably, the ARKit framework received an update in February that included image recognition capabilities, which has been utilized in the application. This meant that is was being used in its beta stages for this project and not a lot of previous work had been done with it.

The image recognition was used in the application to provide an anchor point for the different 3D models to create a correct mapping each time, which was a very important aspect of the application. The 3D models had to be mapped to their physical counterpart and the ARKit framework did not cooperate perfectly all the time. The image that was being used from the beginning was not the best, and when swapped to a recommended image by Apple the performance seemed to improve. Even when the mapping was off by a few centimeters it became quite obvious that they did not match their physical counterparts, and this became even more evident for smaller components.

The performance over time of the application also had issues. When using the application over longer periods of time the phone it was running on became very hot and the performance of the ARKit framework seemed to diminish. This created both drifting of the 3D models and a reduced frame rate.

A limitation with the application as of this moment is its scalability. The usage of an image as an anchor point to create the augmented world re-

lies on the different separator components having the same layout on each separator location. In the real world this is not the case, and in a lot of locations the separator can have unique setups. With the current solution this would mean that each location has to be manually mapped and laid out. This is not really a feasible situation considering how much time and effort this would take. There is also a scalability concern when it comes to adding each alarm that a separator can have and the corresponding instruction sequences. The course of action to mend the scalability issue for the alarms would most likely be to create a service that has a database of all alarms, and a smart and intuitive way of adding more over time.

7.4   Future work

There are plenty of things that could be done in to the AR application, both improvements to the features that exists in the current version of the application but also new features and ideas that could be added to the application. Improvements to the current features within the application feels more hindered by the current technology than anything else, compared to adding new features which was more hindered by the scope of the thesis. Looking at improvements to the current application there are new and coming technologies that could take its features one step further.

One new and improving technology is AR glasses, such as Microsoft's HoloLens, which would allow the user to have both of their hands free and at least in theory, provide a much better field of view compared to a phone.[28] However, at the current state of technology, no wireless AR glasses are able to provide a good enough field of view to be considered for this thesis, but when the technology improves it could further improve the application.

Another technology that could improve the application is object recognition, which works similar to image recognition but can detect 3D objects instead of only 2D images. This would allow the application to scan the separator directly instead of scanning an image that maps the 3D objects around it. If the application could recognize the different components of the separator, then it could handle different types of separator layouts without the need to manually map the different components. The optimal solution would be that the ARKit framework supported object recognition. There are already some companies that have functioning object recognition that can work for mobile solutions, such as Vuforia.[29] Vuforia can detect and track smaller objects and create a virtual 3D model as an overlay over its physical counterpart. This is quite similar to how it is done manually in

the current prototype. At Apple's developer conference in June 2018 it was announced that the next version of ARKit will include object detection and is available in the beta version of iOS 12 [30].

A large feature that was discussed during the project was the usage of real-time information in the troubleshooting process. This should be possible to do by extracting the correct information from the PLC, however this would completely change the way the application connects to the PLC to retrieve the separator alarms. Instead of having a one time connection a more stable and ongoing connection would have to be established that could continuously feed the application with real-time information. The real-time information could become useful during the troubleshooting process by, for example, quickly display temperatures and pressures of different components, and perhaps indicate dangerous levels to the user when necessary. This could all be displayed to the users without them needing to connect external sensors and readers, as they have to do today.

If real-time information was implemented in the application another idea that came up was to not only use the application as a troubleshooting tool but also use it before the alarms on separator go off. Applying real-time data to maintenance functionality the application could be a perfect match. By simply looking at the separator through the application, all information could be displayed and points of concern could be highlighted as well. A more effective maintenance strategy could even reduce the amount of breakdowns and lead to less need for troubleshooting alarms in the long run.

CHAPTER 8

Conclusion

The purpose of this master thesis was to explore the possibilities for AR as a tool in the troubleshooting process of separators for people without expert knowledge. In addition to the main purpose, two sub-questions that tangent the purpose were also asked:

- Could AR be used to reduce the workload for well trained service technicians?

- Could AR be used during the training process of new service technicians?

The end product of this master thesis is an AR application that can assist people with troubleshooting alarms on a separator. Based on the result of the final user test the application is adequate for getting simple troubleshooting instructions and finding the corresponding component on the separator. Using this technology might reduce the workload for well trained service technicians indirectly by transferring the work to an inexperienced individual with the AR application helping them. The participants in the final user test showed positive consensus toward the idea of using the technology during the training process of new service technicians.

With that said, the AR technology has some issues with inconsistent tracking and drifting. The small screen and field of view of the smartphone is another problem, but future AR technology like AR glasses might improve both tracking and field of view.

References

[1] M. Hermann, T. Pentek, and B. Otto, "Design principles for industrie 4.0 scenarios," *2016 49th Hawaii International Conference on System Sciences (HICSS)*, pp. 3928–3937, 2016.

[2] R. T. Azuma, "A survey of augmented reality," *In Presence: Teleoperators and Virtual Environments 6, 4 (August 1997)*, vol. 4, pp. 355–385, 1997.

[3] "IKEA place." `https://itunes.apple.com/se/app/ikea-place/id1279244498?mt=8`. Accessed: 2018-05-26.

[4] "ARKit - apple developer." `https://developer.apple.com/arkit/`. Accessed: 2018-02-28.

[5] "ARCore - google developer." `https://developers.google.com/ar/`. Accessed: 2018-05-26.

[6] L. Chen, W. Tang, and N. W. John, "Real-time geometry-aware augmented reality in minimally invasive surgery.," *Healthcare Technology Letters*, 2017.

[7] J. A. Erkoyuncu, I. F. del Amo, M. Dalle Mura, R. Roy, and G. Dini, "Improving efficiency of industrial maintenance with context aware adaptive authoring in augmented reality.," *CIRP Annals - Manufacturing Technology*, vol. 66, pp. 465 – 468, 2017.

[8] "Alfa laval - our company." `https://www.alfalaval.com/about-us/our-company/`. Accessed: 2018-05-26.

[9] "B&r: Industrial automation — perfection in automation." `https://www.br-automation.com/en-au/perfection-in-automation/`. Accessed: 2018-05-26.

[10] P. Kriesche, "Humans vs. machines – who will manage the factory of the future?," *RC TOM Challenge 2017*, 2017.

[11] "File:industry 4.0.png." `https://commons.wikimedia.org/wiki/File:Industry_4.0.png`. Accessed: 2018-06-26.

[12] M. Wallergård, "Virtual reality & augmented reality - en kort historik," January 2018.

[13] ISO, "Ergonomics of human-system interaction – Part 210: Human-centred design for interactive systems," standard, International Organization for Standardization, Mar. 2010.

[14] M. Wertheimer, "Laws of organization in perceptual forms," *A source book of Gestalt psychology*, pp. 71–88, 1938.

[15] K. Koffka, *Principles of Gestalt Psychology*. Harcourt, Brace and Company (1935), 1935.

[16] D. Norman, *The design of everyday things*. New York: Basic Books, 1988.

[17] E. Fagerholt and M. Lorentzon, "Beyond the HUD - user interfaces for increased player immersion in fps games," tech. rep., Department of Computer Science and Engineering, Chalmers University of Technology, September 2009.

[18] "ARKit — apple developer documentation." `https://developer.apple.com/documentation/arkit`. Accessed: 2018-02-28.

[19] "SceneKit — apple developer documentation." `https://developer.apple.com/documentation/scenekit`. Accessed: 2018-02-28.

[20] "SceneKit - apple developer." `https://developer.apple.com/scenekit/`. Accessed: 2018-02-28.

[21] "Alfa laval - separators." `https://www.alfalaval.com/products/separation/centrifugal-separators/separators/`. Accessed: 2018-05-28.

[22] "Programmable logic controller - wikipedia." `https://en.wikipedia.org/wiki/Programmable_logic_controller`. Accessed: 2018-02-28.

[23] "The "how might we" note taking method." `https://designsprintkit.withgoogle.com/methods/understand/hmw-directions/`. Accessed: 2018-02-28.

[24] "Figma: the collaborative interface design tool.." `https://www.figma.com/`. Accessed: 2018-02-28.

[25] J. Nielsen and K. T. Landauer, "A mathematical model of the finding of usability problems.," *CHI '93 Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems*, pp. 206–203, 1993.

[26] "Why you only need to test with 5 users." `https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/`. Accessed: 2018-05-27.

[27] . E. H. H. Kaya, N., "Relationship between color and emotion: A study of college students," *College Student Journal*, vol. 38, no. 3, pp. 396–405, 2004.

[28] "Microsoft hololens — the leader in mixed reality technology." `https://www.microsoft.com/en-us/hololens`. Accessed: 2018-05-24.

[29] "Object recognition." `https://library.vuforia.com/articles/Training/Object-Recognition`. Accessed: 2018-05-24.

[30] "Apple unveils arkit 2." `https://www.apple.com/newsroom/2018/06/apple-unveils-arkit-2/`. Accessed: 2018-06-19.

APPENDIX A

Testplan

A.1 Purpose

The purpose for this test is to evaluate AR as a tool for troubleshooting separator alarms. The test will performed in a test environment using an AR prototype to assist the testers during the alarm troubleshooting process. The aim with the test is to see if this prototype can be a useful tool for service technicians with no or limited prior knowledge of the troubleshooting process.

A.2 Selection of participants

The end users of the application are people without experience of troubleshooting separator alarms. This means that the ideal participant is one who has no experience with being a service technician. People with experience with the separator will also be adequate testers, since they can provide valuable knowledge of the process.

A.3 Data collection

During these tests the focus is on the subjective data only. This is because the objective data, such as the completion time for a test, is not very relevant, especially since it is not really possible to compare the completion times with the application to a more manual troubleshooting process. The subjective data is more important, as the goal with these tests are to figure how useful the tool can be, and that is mostly up to how the user experience

and feel. Subjective data will be collected by using both a questionnaire to receive quantitative data as well as an interview focusing on the qualitative data. Testers will also be asked to think aloud during their tests, and these thoughts will also be written down.

A.4 Test tasks

The tester will have one major task during the test: troubleshoot all the alarms in the alarm list. Each alarm has a set of instructions that the tester should perform. Since some instructions include removing or disassembling parts of the separator, they only need to say out loud what they would have done with the component instead of actually doing it. The tester can't move on to the next instruction before they've been cleared to do so by the test leader.

A.5 Structure of the test

Phase	Part of phase	Materials	Time
Briefing	An introduction to the tester explaining the purpose of the test as well as an quick introduction introduction of the material used during the test.	A list of notes which will be utilized during the introduction.	2,5 min
Test-tasks	Perform the tasks that are shown within the application.	Separator, Image & AR application	7,5 min
Debriefing	The tester is given a form with a number of questions to answer. After that, the tester will be interviewed.	A computer with the questionnaire. Another computer to write down notable answers from the interview.	5 min

Table A.1: The structure of the test

A.6 Prepared interview questions

- Q1. How was the experience of finding the first component with AR?

- Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?

- Q3. Was the pointer helpful when finding the components?

- Q4. Was the text box floating above the components helpful when finding the components?

- Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?

- Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?

A.7 Questionnaire

Personal information:

- Q1. Age

- Q2. Between 1-5, How familiarare you with the troubleshooting process?

- Q3. Are you familiar with the separator?

- Q4. Have you used Augmented Reality before? (*Yes/No*)

Test-related questions:

- Q1. Between 1-5, how confident are you of performing a troubleshooting after this test?

- Q2. Between 1-5, how helpful do you think this kind of solution can be for troubleshooting alarms?

- Q3. Could you see this kind of solution being used to reduce the workload for well trained service technicians? (*Yes/No*)

- Q4. Could this application be used for training purposes? (*Yes/No*)

APPENDIX B

Post test interviews

B.1 Participant 1

Observation
Struggled with understanding the pointer initially.
Think Aloud
More data could be sent to the phone from the PLC which would mean that you don't always have to be close to the separator.
Q1. How was the experience of finding the first component with AR?
Without further instructions it was a bit hard to find it, but with a quick explanation it was easy to understand.
Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?
Yes it is a good idea, it would be good to have perhaps even more detailed animations.
Q3. Was the pointer helpful when finding the components?
The pointer is helpful when you are finding components that are not inside the phones view.
Q4. Was the text box floating above the components helpful when finding the components?
It might not be the best, it can cover the screen.
Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?
No I didn't notice.
Q6. Is there anything you feel is lacking in the application that

could improve the overall performance and user experience of the application?
The core idea is very good, but the behind the scenes is very important.

B.2 Participant 2

Observation
The tester has trouble with finding the first components. Moves very close to the components to see them. The animations seems to greatly improve the testers ability find the component. After getting the basic idea, the tester can use the application with ease.

Think Aloud
Messages next to the alarm code would be helpful, especially if you are experienced with the machine, you learn some specific alarms that are frequent.

Q1. How was the experience of finding the first component with AR?
The pointer helps to find the component.

Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?
The animation helps to illustrate the instruction (if done correctly).

Q3. Was the pointer helpful when finding the components?
The pointer is good to find the components.

Q4. Was the text box floating above the components helpful when finding the components?
The text box is very helpful to find the components, could also be helpful to find specific components even when no alarms are present.

Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?
It might have helped, I did not notice it.

Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?
The AR needs to be precise and should not drift.

B.3 Participant 3

Observation
This tester has expert knowledge of the separator and is focused on the

instructions and their incompleteness. Seem to find the components quite easily, but this can be because of the testers previous knowledge of the separator.

Think Aloud

The instructions are incomplete. This could be useful for learning about the separator, but it's useless for experts (experienced service technicians).

Q1. How was the experience of finding the first component with AR?

Pretty good.

Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?

They complemented the instructions, but the instructions were incomplete. There should have been many more steps between each component and instruction.

Q3. Was the pointer helpful when finding the components?

Yes.

Q4. Was the text box floating above the components helpful when finding the components?

Yes.

Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?

Yes, a bit.

Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?

As said before, the instructions were too few. Many dangerous steps were overlooked and every safety precaution should be shown to the user. Especially if they are inexperienced.

B.4   Participant 4

Observation

Had an easy time finding the components, since the pointer worked just like in video games the tester had played before.

Think Aloud

The short description of the alarm is missing, the alarm code is not enough.

Q1. How was the experience of finding the first component with AR?

It was easy. It was showing the way like a video game.

Q2. What are you thoughts on the animations on some of the

components? Did they complement the text instruction?
It helps if it is done correctly.

Q3. Was the pointer helpful when finding the components?
The arrow is good.

Q4. Was the text box floating above the components helpful when finding the components?
The text box is nice when finding the correct position and helps with the naming.

Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?
Perfect, it worked.

Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?
More information in the application, so you don't have to use both the HMI and the application.

B.5   Participant 5

Observation
Is not looking directly at the components all the time. Trouble understanding how AR works.

Think Aloud
This application is too simple for expert service technicians, but can be used for teaching.

Q1. How was the experience of finding the first component with AR?
It worked good, the highlighting of the components.

Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?
Easy to understand.

Q3. Was the pointer helpful when finding the components?
The pointer is helpful.

Q4. Was the text box floating above the components helpful when finding the components?
It is helpful if you don't know the components.

Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?
Did not notice.

Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?
The name of the alarm.

B.6   Participant 6

Observation
The tester has contributed to the project and the instructions, so the tester knows how the application works. Has no problems using it.
Think Aloud
Showing the already checked components in green is a good type of feedback. Makes it easy to look around and remember what components you've already looked at.
Q1. How was the experience of finding the first component with AR?
Quite easy, it was well indicated.
Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?
The animations look good, they show what the instructions say. The use of color showing already checked components in green is easy to understand. Simple, but effective and you can build upon it to show more complex animations.
Q3. Was the pointer helpful when finding the components?
The pointer is helpful, especially if you don't know the components.
Q4. Was the text box floating above the components helpful when finding the components?
This is good.
Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?
No.
Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?
Link spare parts to the application.

B.7   Participant 7

Observation
Didn't understand that the pointer was there when the phone didn't move.

Later when the tester understood that the pointer was there, the tester still didn't move the phone, so the pointer looked like it pointed straight down when it pointed down and back. This resulted in the tester thinking the pointer was pointing at another component than it really was.

Think Aloud
The animations work good to help the instruction, more alarm information should be in the application. Using more texture on the 3D models will help with finding the components.

Q1. How was the experience of finding the first component with AR?
It was easy to understand the instruction, did not find the component directly.

Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?
When it works correctly it is good.

Q3. Was the pointer helpful when finding the components?
No, might be need more effects, like more colors or shadows, to make it better.

Q4. Was the text box floating above the components helpful when finding the components?
Yes.

Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?
No.

Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?
More alarm information. The level of detail in the models.

B.8   Participant 8

Observation
Has no notable problems finding the components.

Think Aloud
This looks nice. It's different than using the small screen that is used now.

Q1. How was the experience of finding the first component with AR?
A blinking animation could improve the experience, otherwise it worked good.

Q2. What are you thoughts on the animations on some of the

components? Did they complement the text instruction?
It worked good.
Q3. Was the pointer helpful when finding the components?
It is good. Use shadows to make the 3D-stand out more.
Q4. Was the text box floating above the components helpful when finding the components?
It was too big at first.
Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?
No.
Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?
The text box might enlarge when you press it.

B.9 Participant 9

Observation
Stood by and looked at the previous tester, so didn't have the same initial difficulties as the other testers.
Think Aloud
This is like a visual instruction manual in 3D space.
Q1. How was the experience of finding the first component with AR?
It was easy.
Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?
Very good.
Q3. Was the pointer helpful when finding the components?
The pointer might improve with another shape, blinking.
Q4. Was the text box floating above the components helpful when finding the components?
Could be risky in confined space.
Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?
No.
Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?

No.

B.10 Participant 10

Observation
Looks lite the tester understands the functions intuitively.
Think Aloud
This application can be used during basic troubleshooting by users with little knowledge of the separator, thus reducing the workload for the experienced service technicians as they don't have to be contacted for basic troubleshooting.
Q1. How was the experience of finding the first component with AR?
Pretty easy, but the screen is too small, which makes the Field of View too small.
Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?
Yes, they worked.
Q3. Was the pointer helpful when finding the components?
Yes.
Q4. Was the text box floating above the components helpful when finding the components?
Yes.
Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?
Not really, but it could be useful.
Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?
No.

B.11 Participant 11

Observation
Was a participant in the previous test and already has an understanding of how the application works, especially using the pointer.
Think Aloud
Friction coupling cover animation was intuitive, you really understood how you were supposed to remove it.
Q1. How was the experience of finding the first component with

AR?

Yes, it was more or less "plug and play".

Q2. What are you thoughts on the animations on some of the components? Did they complement the text instruction?

Yes.

Q3. Was the pointer helpful when finding the components?

Yes, when you understand how it works.

Q4. Was the text box floating above the components helpful when finding the components?

It was useful.

Q5. Did you notice the animation of the text box between two components? If so, did it help you navigate to the next component?

No.

Q6. Is there anything you feel is lacking in the application that could improve the overall performance and user experience of the application?

No.