Augmented Reality in Automotive Workshops: A Design Science Case Study

Bachelor of Science Thesis in Software Engineering and Management

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Gothenburg, Sweden 2019

This paper presents a research on application of augmented reality within automotive industry.
In order to evaluate the application of AR tools within a workshop context, we present a tool which guides the mechanics throughout the given task.
The research was conducted in cooperation with one organization working with big scale automotive companies on the topic of automotive diagnostics.
The evaluation of the tool displayed the effect AR tools have on assembly work.
The observations of the application of the tool are our contribution to the research of using AR within automotive industry.

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***Abstract*—Augmented Reality (AR) is an evolving technology researched and applied in many areas to help support and guide work. One field in which the application of AR in practical usage is not common is automotive industry. To help minimize this gap, the presented research aimed to evaluate the need for AR in automotive industry and present an artefact applicable in simple workshop environments. Three semi-structured interviews with automotive technicians were performed to identify the issues encountered when working with connectors in a tight space and to design a prototype which could help mitigate them. The interviews highlight the need of a mobile AR tool within an industrial setting and the evaluation of the tool displays the benefits brought by introducing such technology in a workshop. An AR application has been developed and evaluated by mechanics and industry experts working with connectors in a case study, where the application was put to use to observe its effect on mechanics' ability to solve workshop tasks. The findings showed that the usage of a mobile tool simplifies the task and decreases the time spent on assembly tasks by providing information on-spot. The study concluded that AR technology simplifies tasks such as identfiying markings on cable connectors and suggests that further research in this direction is needed to help further develop this area on a larger scale.**

***Index Terms*—augmented reality, industrial AR, AR in automotive**

I. Introduction

Augmented Reality (AR) is a technology used to supplement the real world by superimposing virtual objects on a user's view of their surroundings, appearing to coexist in the same space, thus enhancing one's perception of reality. It is a interdisciplinary field engaging signal processing, computer vision, computer graphics, user interfaces, human factors, wearable and mobile computing, and information visualization [1]. An AR system's main function is to combine real and virtual objects in a real environment, run interactively and in real time in three dimensions, aligning real and virtual objects with each other [2] [3].

AR is a part of the concept of 'mixed reality', alongside augmented virtuality and virtual environment, where real objects and surroundings are replaced by their virtual correspondents [4]. Unlike virtual reality (VR), which requires the user to inhabit an entirely virtual environment, AR uses the real world environment and overlays virtual information on top of it, providing assistance in everyday activities [5]

The beginnings of AR date back to the late 1960s with Sutherland's "The Sword of Damocles" virtual reality system which incorporated a head-mounted display [6]. The fundamental idea behind Sutherland's research was to present the user with a perspective image which changes as she or she moves, creating an illusion of a three-dimensional displayed object, moving the image according to the user's head movements.

Research on augmented reality has found uses in a variety of matters, such as business, warfare and medicine. For example, in 1960s and 1970s, the US Air Force established a laboratory to develop flight simulators and head-mounted displays which would facilitate learning and performance in military aircraft [7]; in 1960s, General Electric developed a simulator that was adapted for lunar mission simulations [8]; in 1970s, researchers at MIT developed a spatial data management system using videodisc technology [9]; in mid-1980s, NASA Ames Lab started a development of a system that would simulate the environments and the procedures astronauts would be engaged in during spaceflights [8].

A vast majority of literature focuses on exploring the applications, usage and benefits of augmented reality technology in the aerospace industry, while a smaller number of literature describes the application of AR in automotive and other industries. Its main functionality is set in the areas of assembly and training.

A. Motivation

Today's products are getting more and more complex [10]. Consequently, as the technology advances, so does the required documentation, possibly resulting in excessive amount of instructions [11]. While documentation describes the order in which operations are to be performed and explains the fundamental parameters, workers can face difficulties interpreting the information or following complex processes [12]. The increasing technological complexity is reflected in higher costs of new product development. This poses increased stress on workers, leading to working longer hours to meet the requirements of the job and increasing volumes of work, which can have negative effect on physical well-being of an employee, potentially causing occupational injuries and illness [13].

The potential of AR increases with the complexity of the product [11] – complex products require extensive documentation which may be hard to follow through. AR can replace traditional documentation and provide information relevant to the process by augmenting the environment in a situation-sensitive manner through the usage of stationary or mobile systems [14], allowing the instructed person to see the instructions visually portrayed in front of their eyes, saving time and resources [15]. Such technology has been applied in the aerospace industry and industrial plants, with main applications in training, maintenance, repairing and inspection [14] [16] [17] [18], while in automotive industry it is applied for design and testing purposes [14] [19]. However, there is a lack of AR technology in assembly processes of automotive industry. As portrayed by the aerospace industry, AR offers many benefits related to the manufacturing tasks. AR-based manufacturing guidance is more effective than alternative guidance forms [20].

Similar technology has been applied in a number of industries and its benefits have been proven; however it has not been widely applied and this research aims to contribute to the field.

B. Context

This thesis was conducted in collaboration with an industrial partner, Diadrom. The purpose of this research is twofold: to evaluate the need for application of AR technology within the manufacturing area of automotive industry and to design an artefact employing AR technology. To expand this area, we propose an implementation of an AR system aimed at being used in workshops to help automotive mechanics during manufacturing and maintenance service by identifying objects and displaying components through a smart device.

C. Research Questions

To support the presented study, we propose the following Research Questions (RQs):

- RQ.1: What features would the automotive mechanics need from an AR artefact to improve their workflow?

The goal of RQ.1 is to investigate the requirements for a creation of an AR artefact for it to be applicable to the maintenance area in the automotive industry. This will be answered through literature review and interviews with practitioners in the first phase of the research. Based on the findings of RQ1, we propose RQ2:

- RQ.2: How does the presented AR artefact affect maintenance work of automotive mechanics?

RQ.2 aims at evaluating the artefact within an industry context through a workshop with practitioners. The results will help narrow the present research gap on usage of AR in the automotive industry.

The automotive industry is a broad term - it encompasses design, manufacturing and assembly of motor vehicles, including most components, such as engines and bodies, but excluding tires, batteries, and fuel [21]. To tailor this topic to the scope of a Bachelor thesis research, we have narrowed the scope of the problem to focus on the issue of the identification of cable connectors' pin-outs' numerical markings.

In some cases it may be difficult for automotive mechanics to identify each individual connector's pin-out. In this sense, AR technology could prove especially useful when working with small connectors, in poor lighting and with small markings. Considerable amount of time is spent on searching and studying instructions, resulting in increased time spent on the task, decreased performance and worker stress [22]. AR technology could facilitate this process by interactively providing instructions on steps that need to be undertaken [23].

D. Structure

The thesis is structured as follows: Section II covers related literature on the problem domain; Section III describes the employed methodology process to collect and analyze data, in addition to describing the evaluation steps of the resulting artefact, and identifies the limitations of the study; Section IV reports the data collected through interviews and their relation to the set RQs; Section V discusses the reported results and their relations to the covered literature in addition to suggesting future work; Section VI discusses the threats to validity of this research and undertaken mitigation strategies, Section VII contains our final thoughts.

II. Related Literature

Syberfeldt et al. [24] evaluated a number of approaches for realizing augmented reality in a shop-floor and discussed advantages and disadvantages of different solutions from an operator's perspective. They have also identified the importance of utilizing the full potential of the AR technology and its implementation in industrial shop-floors. The authors note that, in order to accommodate operators to the fast change, the development of efficient decision support systems is of uttermost importance. They present and evaluate a number of solutions for realizing augmented reality in the context of the industrial shop-floor, from an operator's perspective. Four prototypes were developed to be used in the study: video-based glasses, optical glasses, video-based tablet, and spatial projector. Although those mediums are most commonly used for entertainment purposes, all prototypes were designed for an industrial scenario. The prototypes were applied in various scenarios, as not every prototype is applicable in every scenario. Each solution was evaluated through workshops and interviews with representatives of seven companies within West Sweden. Each scenario was summarized in the form of advantages and disadvantages reported by participants. The participants reported ease of use and familiarizing with the technology, in addition to perceived increased efficiency with augmented reality. However, some participants said that efficiency of AR must be proved and that the complexity of the task must be high enough, or the user might deem the technology pointless.

Schwald and de Laval [25] presented an AR system for training and assisting in maintaining equipment in an industrial context. Using an optical see-through Head Mounted Display (HMD) to apply AR technology, the user was guided step by step through training or maintenance tasks. They encountered issues such as the hardware carried by the user limiting user's movement, high latency and poor data exchange between sub-parts of the system. Based on the results, they concluded that such AR products are a promising method that could be used more actively in the maintenance and training applications.

In collaboration with Boeing, Richardson et al. [26] developed an AR study to evaluate three different methods of presenting work instructions. They compared traditional model-based work instructions (MBI) with augmented reality work instructions in an assembly of an airplane wing. The three methods were Desktop MBI, Tablet MBI and Tablet AR. Both Desktop and Tablet MBI were designed to mimic the instructions on a stationary display, with the only difference being the location of the tool. Desktop MBI was placed in a nearby room, while Tablet MBI was mounted on a nearby mobile arm and could be moved around the room. Tablet AR was identical to Tablet MBI, but instead of displaying instructions, the instructions were presented using AR. The study reported reduced time on task and greater emphasis on each task for the Tablet AR method, while the Desktop MBI and Tablet MBI modes caused participants to spend a significant amount of time traveling and confirming information.

Regenbrecht et al. [11] developed prototypes of AR applications in the areas of servicing and maintenance, design and development, production support, and training. Within servicing and maintenance they worked on prototypes to help with space station filter change, engine maintenance and tram diagnosis; within design and development they created prototypes for airplane cabin design, collaborative design review and cockpit layout; within production support they created prototypes for fuse placement, picking and wiring; and within training they created a prototype for driver safety training.

German and European Aerospace industry initiated the space station filter change project. The goal of the project was to evaluate the application of AR technology in space. To test the validity of the concept, a prototype for providing instructions and support for monitoring the condition of the air filter, and possibly changing the filter, was developed. In collaboration with developers from the client group, a wearable AR system employing a head-mounted display was developed, and the instructions were deployed by aligning 2D content in 3D space. The research involved the implementation of an optical see-through solution and its connection to a content delivery system. The system was successfully demonstrated at an international aerospace fair. However, due to the rigorous requirements of the aerospace industry, the presented system was not applied in space.

Within the automotive industry, Regenbrecht et al. [11] worked on implementing a prototype application for a Mercedes-Benz SL engine. The motivation for this research was closing the gap of spatial separation between the object under inspection and the data obtained by the diagnosis. Similarly to the space station case, an HMD solution connected to a portable PC was chosen. User's position and orientation was tracked using a marker-based approach. They presented four types of data: a) maintenance and repair instructions represented as textual and pictorial information, b) pre-recorded video instructions, c) 3D models with predetermined animated sequences as overlays, and d) a video/audio link to an expert technician as an example of remote technical assistance. They discovered that information provision is the biggest challenge in creating a guidance system; appropriate information must automatically be selected from the data system, the user interaction must be simple and intuitive, multimedia content must be created and kept up-to-date, and multimedia information must be correctly aligned with the object. In addition, they pointed out that it must be considered which data is important for displaying and how to place the information in comparison to the object being observed.

In addition to the car maintenance example mentioned previously, Regenbrecht et al. [11] worked on developing a prototype for tram maintenance. Two challenges were identified: the AR system must be wearable due to the size of the vehicle and distance between components, and the information system must be linked to the existing diagnosis system. To satisfy these requirements, a wearable AR system using a notebook computer was created. The system was tested in a laboratory setup simulating a real tram environment. The hand-held computer served as the main interaction interface to the diagnosis system, using arrows and explanatory texts in the augmented view to direct the user to the target diagnosis object. However, there was a number of shortcomings of the system in relation to real world application, such as impractical tracking instrumentation of the environment, heavy wearable unit, and lacking performance of the wireless network for a real-world environment.

Airplane cabin design and development involves customers as an integral part of the design team, as airplanes are designed according to the customer's needs. The design process involves many simulations utilizing both physical and digital mock-ups, where the geometric properties can be accurately stimulated. However, physical properties such as temperature, speed, air flow and air pressure are more complicated to stimulate accurately, and their physical mock-up is very complex and not cost effective. Regenbrecht et al. [11] used Computational Fluid Dynamics (CFD) data to visualize the physical properties in the form of colors, which can be used to interpret the level of cabin comfort. In this manner, AR allows for an easy combination of the real space, cabin objects and CFD data sets through a HMD. The system was put in use at the client company, but further modifications were planned.

The design and development process of a complex product involves many iterative engineering steps, resulting in frequent meetings to make design decisions, cover all requirements and find the best solutions. The meetings incorporate digital models, physical mock-ups and prototype models to evaluate the design and development process. As Regenbrecht et al. [11] have concluded, the creation of the physical models is time consuming and expensive, and AR can offer the opportunity to integrate visuals into the meeting environment, with the objects appearing to be present in the environment. The authors evaluated a prototype system which supported up to four people to attend a meeting wearing HMDs and using virtual models. However, the research focused on small objects, suggesting need for further development to support visualizing larger data sets and better integration with product management systems.

As described in [11], Regenbrecht et al. developed an AR HMD tool to help with designing airplane cockpits. The cockpits must be designed carefully due to the number of displays and controls. The authors presented an artefact which superimposed visual elements on a metal whiteboard containing magnetic markers, which allowed the designers to experiment with various arrangements of cockpit elements. Their artefact was usable only in the early design phases due to its lack of access to the dynamic data, limitations of available space for superimposing elements on the whiteboard and their arrangement in space.

III. Methodology

To give answers to the suggested research questions, this research applies the design science research methodology (DSRM) [27]. DSRM emphasizes contributing to the applied domain [28]. Due to the focus of this research being identifying the contribution and benefits of a tool, evaluation is a big part of the research. Evaluation is an essential activity in conducting design science research [29].

A. Company description

This research was conducted as a case study at the company Diadrom, an expert consultancy company with a focus on the area of diagnostics of products with embedded software. Founded in 1999, majority of their customer base is in the automotive sector, in addition to holding customers within industrial machinery, defence, security and public transport sectors. The roles involved in this study are managers and automotive mechanics from partner car manufacturing companies as the aim of the tool is to help with performing tasks within an automotive workshop setting. For privacy reasons we are unable to give the exact names of the companies, and will therefore be kept anonymous. Throughout this paper, Diadrom will be referred to as C1, and the partner company as C2.

B. Research approach

To perform the research, an iterative DSRM proposed by [27] was followed. The DSRM described in [27] consists of six steps important for successful creation of artefacts: problem identification, definition of the objectives for a solution, design and development, demonstration, evaluation, and communication [27]. Our research methodology was based on the suggested steps, tailored to the needs of the research. The research consisted of seven steps, two cycles and one iteration, as portrayed in Figure 1:

- Problem definition: The specific research problem must be defined and justified;
- Research: A literature review must be performed to provide the background and context for the research in addition to portraying the importance of the research;
- Requirements elicitation: Identified problem must be broken down into objectives or requirements;
- Design and development: The artefact will be improved by the researchers based on findings from the previous steps;
- Validation: The artefact will be applied to demonstrate its factor in solving one or more instances of the presented problem;
- Evaluation: The usage of the artefact during workshops will be evaluated, observing and measuring how well the artefact fulfills elicited needs. This activity can lead to iterating back to an earlier step in order to improve the effectiveness of the artefact;
- Communication: A conclusion where the problem, its importance and solution are communicated.

1) First cycle: Main goal of the first cycle was to define and justify the research problem and the research objectives, and to reflect on their importance [27]. An extensive literature review was performed to provide the background and context for the research to support the presented problem, in addition to acting as a starting point for the DSRM. Main area of interest were papers covering application of augmented reality within automotive and aerospace industry. However, due to the lack of published papers in this area, examples from other similar industries were covered to give a detailed overview on the usage of AR technology in mechanical industries. The literature review has showed that AR tools are not widely applied in the automotive industry. In collaboration with the partner company C1, a task often performed by automotive mechanics which at first glance seems simple, but in fact can cause a lot of issue if performed incorrectly has been identified - connecting wires and connectors. C1's familiarity with automotive industry and experience with diagnostics has served as a basis for identifying possible issues in this area. Based on this, a design of an artefact which could be used by automotive mechanics to help with performing the task was designed. To support the theory, in addition to supporting requirements elicited from literature review, possibly discovering further requirements, and evaluating

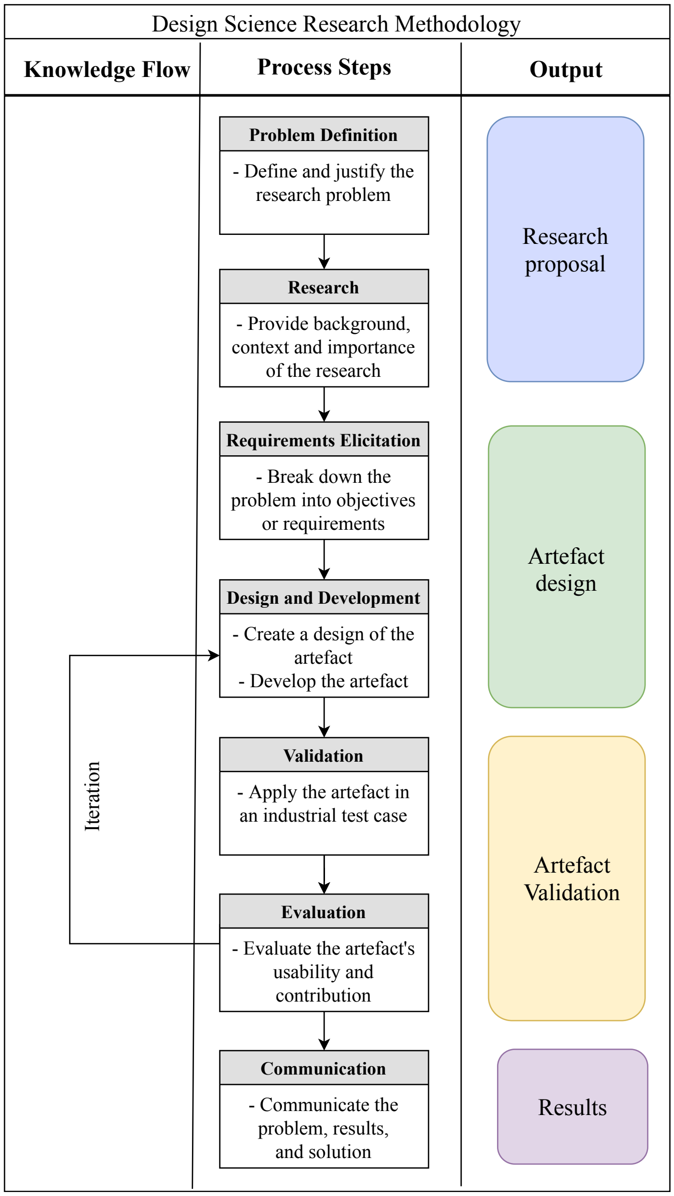

Fig. 1. Design science process used in this research

the proposed artefact design, interviews with three individuals from two different companies were performed. The interviews served as a validation and evaluation step for the artefact, where we have presented the artefact and elicited possible application in an industrial setting. The interviews have affirmed our theories and helped further develop the design of the artefact. To perform the prototype creation, the research iterated back to the design and development step. The purpose of this cycle was to answer RQ.1.

2) Second Cycle: The data gathered in first cycle allowed us to further improve the artefact design and make it comply with the views and needs of the participants. A prototype was created based on the updated design, providing a solution to the main issue identified by the interviewees. The prototype was presented to the interviewees during a case study, where they were asked to apply the artefact in a small test case with identifying numerical markings on connector housings. To observe the effect of the artefact, the participants have been separated into two groups. First group was asked to solve the task without the prototype, while the second group was given the prototype to aid them in the task. This allowed us to observe the differences in task performance. The artefact was presented to the first group following the case study in order to gather participants views and assumptions on how such a tool could have affected the task performance. Participants from both groups were asked for opinions on the presented artefact's factor in solving the problem, in addition to suggesting possible updates to the artefact. However, further improvements were not planned in this research. Instead, implementing additional functionality was left to any future projects that might emerge from this research. The results gathered in this cycle were sufficient to draw a conclusion from. With this case study, answers to RQ.2 were gathered. To conclude the research, we proceeded to the final, communication, step, where the results and their implications were discussed.

C. Data collection

The data was collected empirically, using three short semi-structured interviews [30] with three individuals, and a case study with workshop elements [29] with two individuals from the two aforementioned cooperating companies, see Table I. Focus was set on usability, features and improvements of the artefact. The subjects of the interviews were managers and automotive mechanics. Company C1 was represented by three participants, P1, P2 and P3, while company C2 was represented by one individual, P4. The interviews contained 7 questions, see Appendix A, and lasted approximately 20 minutes. The interviews were audio recorded for later transcription and analysis.

TABLE I
ITERATIONS DATA COLLECTION AND PARTICIPANTS OVERVIEW

Cycle	Data Collection Method	Participants
First	Interview	P1, P2, P4
Second	Case study	P1, P3

An interview guide was developed based on the needs of the research in order to collect similar data from all participants. The goal of the interviews was to support the requirements elicited by the researcher through literature review and to identify additional requirements. A list of predefined questions was created and used, and due to the flexible nature of semi-structured interviews, the researcher was free to seek clarification or offer further explanation if needed [30].

Main advantages of semi-structured interviews are that the interview questions can be further elaborated on with open-ended questions, giving a chance to explore issues that have not been considered initially [31] and issues that arise spontaneously [32], in addition to the researcher being free to ask additional questions depending on the direction of the interview [33]. This increases the validity of the study by allowing for richer data to be collected. However, interviews also have their disadvantages, such as being time-consuming [30]. In order to mitigate this, the interviews were time-boxed to a 30 minutes time frame.

In addition to the questions, one case study [34] was performed in the second cycle. The goal of the case study was to investigate how the proposed artefact affects work in the field of maintenance and how practitioners evaluate it. There exist several different approaches on how to perform observations [34]. A mixed approach was used in this research: monitoring a group of practitioners while taking notes of their behavior, and repetitively asking the practitioners to express their thoughts.

The tool was evaluated through a case study where two participants were asked to identify the numbers on a 6-way Deutsch connector housing. The participants were seated at a desk in a room with poor lighting in order to mimic the environment in which these connectors are usually found, e.g. inside a vehicle. The connector was mounted on a small clamp tool, which allowed for the connector to be freely turned around. Each participant was instructed to find three different numbers on the connector and the time required for the task was recorded. Each attempt was altered as follows: the connector was rotated to mimic the movement of a loose connector within a vehicle and the lighting was manipulated to emulate the workspace when working with different vehicles and hardware set-ups. The time needed to perform the tasks was measured and notes of the participants' behavior and reactions when interacting with the prototype were taken [35]. In addition, the participants were asked to convey their thoughts out loud while performing the task, and audio recorded their answers for later analysis. The artefact was presented to the participants and they were asked to express their opinions on how the tool could have affected their performance. These interactions were also audio recorded and transcribed in the analysis portion of the research.

D. Data analysis

The data analysis procedure consisted in the transcription of the interview recordings into individual documents, an evaluation of the answers and creation of possible categorization of the qualitative data, following the open coding method as described in [36] [37] [38]. The coding schema was created during the analysis, and each transcription was covered multiple times in order to ensure completeness of the coding. As mentioned in [39], humans tend to look for non-existent patterns. To minimize the risks, the coding was reviewed by a researched from the university who has worked on a number of published papers. The aim of the coding process was to identify recurrence of themes and issues addressed in the interviews [39].

TABLE II
LABELS USED FOR INTERVIEW TRANSCRIPTS

Label	**Description**
Issue	Commonly encountered issues in the workshop when working with connectors
Cause	Explains the reasons behind some of the identified issues
Expectation	Interviewee's expectations of the tool's functionality
Suggestion	Interviewee's suggestions on improvements to the tool
Current practices	Description of similar tools and ideas present in the industry
Future work	Interviewee's ideas of possible expansion of the tool's applicability

Five coding labels were decided upon to categorize important sections of the transcripts. The labels were: issue, cause, expectation, suggestion, current practices and future work. The labels and their descriptions are shown in Table II.

IV. Results

Using the insights gained via the presented design cycle, we created an application to guide users through the assembly process. The resulting tool is an AR helper tool which, with the help of a camera on a mobile device, performs image recognition of the object being observed, processes the data from related schematic diagrams stored in a database, and superimposes corresponding visual elements onto the view captured by the camera on the device.

The first iteration aimed at eliciting requirements assumed to be needed by the researcher. The main source of information for this iteration was literature, in which similar scenarios have been described, but applied in different industries and manners. We have identified many issues encountered when working with connectors, e.g. the numbering of pin-outs might not exist or be visible due to dirt or wearing, the markings may be found on the back side of a connector leading the user to wrongly connect the wires when looking at the connector from the front side, or that the connectors and pin-outs may be very small, in addition to being tucked in tight, inaccessible or poorly lit spaces within a vehicle.

To support these findings, we have performed three interviews with managers and automotive mechanics. Two participants were from C1, while the third participant was from C2. The results of interview analysis greatly supported the aforementioned issues, in addition to identifying additional problems and possible solutions, and relating the problem to similar tools and ideas used in the industry. They identified that physical dimensions of the connectors, difficulty to read pin-outs and often missing markings as the biggest issues. In addition, they identified that practitioners use a variety of tools to make a measurement to identify the pin-out, and that physical limitations of a connector do not allow for many re-connects of the wiring, which can damage the connector, see Table III.

The interviewees identified the following as main expectations of the tool's functionality: identifying the connector type, cable colors and pin-out numbering, providing information relevant to the connector housing such as pin-out signal type, and guiding the user through the connecting task. These findings are summarised in Table IV.

TABLE III
MAIN ISSUES WITH WORKING WITH CONNECTORS IDENTIFIED BY THE INTERVIEWEES

Functionality	Nr. of mentions
Missing markings on connectors	3
Physical dimensions of the connectors	3
Difficult to read pin-outs	3
Physical limitations of the connector	1

TABLE IV
INTERVIEWEES' EXPECTATIONS OF THE TOOLS' FUNCTIONALITY

Functionality	Nr. of mentions
Identification the connector type	2
Identification of pin-out numbering	3
Identification of cable colors	3
Displaying data relevant to the connector housing	1
Guidance through connection task	1

Through the interviews it emerged that the participants have not used an AR tool previously, but have seen applications of similar tools. For this reason we have identified that the application must be intuitive and simple to use to not make the user feel overwhelmed. It was also suggested that the tool should be designed similarly to tools used in diagnostics and integrated in the same software environment.

The participants identified that having an interconnected system where a database would store the diagrams and instructions related to the hardware used in the workshop would be the main benefit of the tool. This would allow for quick and simple updating of the system with latest diagrams and instructions whenever new pieces of hardware are introduced. As P3 noted, colors of cables are subject to frequent change, and having such a system would allow for a simple update of the correct information, allowing all users to get the updated instructions at once. In addition, the interviewees identified scaling up the functionality of the tool to identify more objects, such as harnesses and ECUs, would be beneficial as it would help lower the amount of paper instructions being used.

In Table V the main identified issues and their possible solutions which could improve the applicability of the artefact are summarized. However, due to the time available for the research being limited, it was not possible to implement all of them. Instead, this information is being provided as a suggestion for future work to further support the applicability of such tools on a wider variety of tasks.

The presented results give answers to the first proposed research question - the interviewees supported the identified issues and requirements elicited through literature review, in addition to expressing their views on the proposed artefact and the functionality they think would be important parts of the tool.

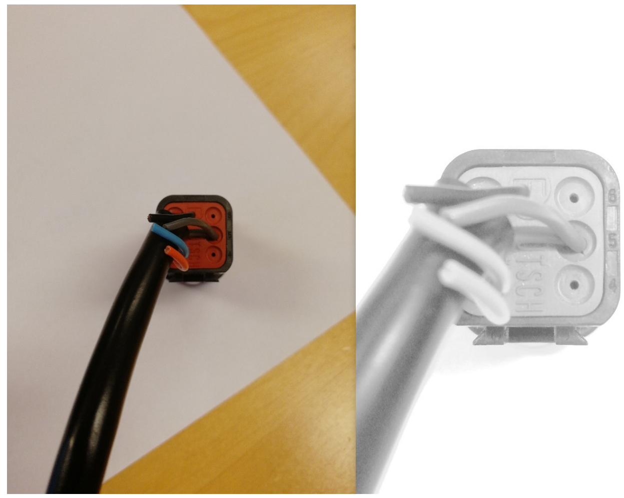

Fig. 2. Left: view of the connector housing before processing. Right: view of the connector housing after processing.

Based on these findings, a prototype was developed. The prototype is an Android application and it requires a camera to function. The camera is used for image capturing. The captured image is processed by using OpenCV's[1] functionality for image manipulation in order to balance colors and make digit extraction simpler, in addition to zooming in the view for easier observation, see Figure 2. The resulting view is depicted in Figure 3. The digits found on a connector are then extracted from the modified image using Tesseract[2]. The identified numbers are displayed on screen in the form of superimposed objects by using ARCore[3]. Due to the nature of the work and possible users' unfamiliarity with AR, the UI was kept simple, containing only the most basic features.

This case study has evaluated two participants' (P1, P4) ability to identify numerical engravings on a connector housing. P1 required on average 25 seconds in two attempts to orientate around the connector and identify the number, with one failed attempt where the participant got frustrated at the task and declared the task "too hard on eyes." P4 required on average 13 seconds to identify the number for each attempt. However, the mimicked environment did not provide a similar experience to working in thigh spaces within a vehicle. The results would presumably be

[1]https://opencv.org/
[2]https://github.com/tesseract-ocr/tesseract/wiki
[3]https://developers.google.com/ar/

different if it was possible to perform the evaluation in an automotive workshop. Observing the participants, we have noticed signs of straining in attempt to closely inspect the connector housing and frustration due to the inability to find the correct digit. The participants also expressed their thoughts during the evaluation and their main remarks were on the visibility and clarity of the numerical engravings, and the strain posed onto their eyes and body as they had to manoeuvre around the connector. Upon being handled the tool and demonstrated its usage, the participants expressed their thoughts on not having to strain one's eyes in attempts to recognize the digits. The tool performs data processing within 4 seconds which is three to four times faster than doing the recognition manually.

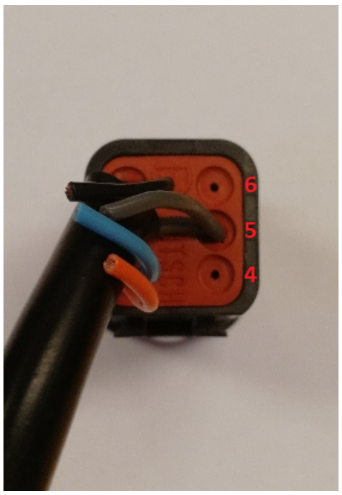

Fig. 3. The view of the connector housing as displayed to the user

V. Discussion

This research has focused on the usage of augmented reality within an automotive workshop setting. The literature covered in Section II showed a research gap on the topic of helper tools in the automotive industry. The identified research gap displayed that AR approach to solving tasks was not applied in automotive industry, while other industrial fields have introduced such tools in a small number of work areas. To fulfill the goal of this research, design science research methodology was used to create and evaluate an artefact which would help evaluate the presented issue. The creation of the artefact employed software engineering practices such as requirements engineering, design, development, construction, and testing of software [40], while the evaluation of the artefact followed guidelines by [32] and [30].

To investigate the research gap, this research aimed to gather opinions from individuals involved in the automotive industry at manager and mechanic levels. The practitioners were interviewed to gather their view on how an augmented tool could enhance the workflow within the context of an automotive workshop (RQ.1). This work highlighted that there is a number of limitations involved in working on an automotive vehicle, such as physical limitations of the hardware, the environment, and human error. The existing literature does not cover these issues, as the literature mostly focuses on assembly of bigger pieces of hardware which do not include smaller pieces of hardware. According to the presented findings, an artefact which would help ease simple assembly tasks by recognizing digits on a cable connector housing and emphasizing the markings by overlaying clear digits over the view was designed, and upon its validation, a tool was developed based on the presented design. The tool was evaluated by practitioners in a test case where the performance of tool was compared to the performance of the practitioners when performing the work manually. The proposed tool acted as a simple helper tool and its effect on the task of enhancing work experience was observed (RQ.2). The presented tool is similar to a number of tools described in the literature, however such tools were evaluated in aerospace industry where they are applied on a larger scale. The manual task execution where the user had to identify markings by looking at the hardware was three to four times slower than the tool's processing ability. As such, we observed that the tool slightly decreased the time spent on identifying the markings on the hardware and therefore allows to perform the assembly task in a quicker way. In addition, as the tool processes the view it is capturing, the user does not have to strain their vision due to e.g. small markings or poor lighting. In this sense, the usage of helper tools can help the workers feel less physically burdened and less frustrated at the tasks, which could increase the efficiency at which the work is being performed.

The results have been collected through interviews and a case study executed with collaborating companies. By following an iterative process of designing and evaluating the presented artifact we were able to identify many issues present in a workshop that could be solved by implementing augmented reality tools in everyday tasks. The requirements were captured by employing interviews following the guidelines by [32], upon which the artefact was created. Evaluation of the artefact was performed by following the guidelines by [30], through which it was discovered that the artefact reduced the time needed to complete the presented task. This finding supports the identified research gap on which the research was based and suggests further software engineering studies to further advance the knowledge on the matter within automotive industry.

Given the possibility, the scope of the prototype would have been increased by introducing additional functionality. Doing so would have allowed for an evaluation of multiple areas of working with hardware in a workshop, resulting in a greater contribution to the field. In addition, this would have encompassed a greater number of potential participants and therefore the research would have evaluated the work of individuals with different expertise.

The presented work differs from the reviewed related literature in sense that majority of research done so far has

TABLE V
IDENTIFIED ISSUES AND THEIR POSSIBLE APPLICATION SOLUTIONS

Issue ID	Description	Functionality
#1	Difficult to read the pin-out numbers	Recognition of the numbering on a connector
#2	Physical dimension of the connector	Recognition of the shape and matching the data to a predefined list
#3	Missing markings on the connector	PREREQUISITE: #2; pull data from database, display the image
#4	Colors of cables	Identify colors of cables, suggest which pin-out which colored cable should be connected to
#5	Impossible to know signal types without documentation	PREREQUISITE: #1, #2, #3; display the data on screen
#6	More information about the connector house	PREREQUISITE #1, #2, #3; allow the user to select an identified pin-out; display detailed information on the selected pin-out
#7	Connection instruction	PREREQUISITE: #4; display connecting instructions on screen

been done on tasks with main characteristic being higher cost. This research contributed to the field with a result that shows the practitioners' anticipation for introduction of similar tools in their work, and that such tools could benefit the practitioners. Given the possibility, the scope of the prototype would have been increased by introducing additional functionality. The presented results support the existence of the identified research gap and suggest further research following the software engineering guidelines to expand the knowledge on the topic and advance the practices used in automotive industry.

VI. THREATS TO VALIDITY

The main threats to the validity of the presented research are discussed in this section.

A. Construct Validity

Construct validity refers to the ability to measure what the research is aiming to measure [34]. In the case of this research, the inexperience of the researcher might have led to poor formulation of interview questions, possibly gathering irrelevant data and not gathering important data. To mitigate this threat, the prepared interview questions were presented for revision to the thesis' academic and industrial supervisors. The artefact developed in this research contained minimal functionality. Due to the time constraint, the artefact was not polished, which has caused some issues during the evaluation phase. Auto-focus and flash on the camera have played a great role in the evaluation. If the auto-focus did not work properly, the evaluation of the application of the tool was set off due to the extra time that was needed to have the application recognize the numbering and properly update the view. This is a great limitation to the study as the evaluation might have resulted in greater differences between task execution with and without the tool, in addition to possibly portraying that the application increases time spent on task. This might have affected the quality of the work negatively.

B. External Validity

External validity refers to the ability to reproduce the research, therefore generalizing the results to other studies [34]. The undertaken steps and methods which were followed in this research are documented in section III; therefore, the research can easily be reproduced. However, the presented research was performed in collaboration with a consultancy company. Due to the nature of consultancy work, there were no direct partners involved which could partake in the research. Therefore, we encountered a limitation regarding sample selection. The limited number of participants posed a threat on the research, as we were unable to select a sample with various types of demographics - age, eyesight and familiarity with the topic are all crucial information in this research. The company's bias regarding this topic could be considered a possible threat to the external validity of this research. Their wish to promote their beliefs and ideas on this matter might have influenced the research design and therefore the gathered results and conclusions.

As a bachelor thesis, this research was limited to a 6 week period. The limited time frame available to run the project played a role in narrowing its scope. Due to this, the research had to cover a smaller portion of the presented issue. The developed prototype contained limited functionality, therefore its evaluation could have possibly wrongly portraying the need of solving the presented issue within the industry in general. In addition, there is a possibility the performed literature review has not covered every aspect of the problem being investigated, leading to incomplete assumptions and data, in addition to the design and execution of the research possibly not being performed to their full extent.

C. Internal Validity

Internal validity refers to the effect an individuals might have on the result of the study [41]. When following a transcript coding process, it is expected the researchers might introduce coding bias and possibly misinterpret the data, posing a reliability threat. To mitigate the risk, the researcher discussed the coding process and labels with another researcher experienced in performing transcription analysis.

Another limitation this research has encountered is lack of reliable scientific data. As the research is focusing on issues encountered in industrial context, there is a lack of reliable sources that report issues and evaluation of similar artefacts. The majority of examples are found in online blogs and industrial news pages reporting new technology applications, which might not contain accurate data and therefore misleading the research.

VII. Conclusions

This work seeks to investigate the identified research gap on usage of augmented reality systems within the automotive industry. We have designed a tool to help with cable connector assembly in an automotive workshop. The tool posed as an evaluation piece of the current state of industry and possible effects such tools might have on the work-flow. Throughout this research we have discovered that such technology is anticipated by mechanic personnel and that they see many benefits in using helper tools that guide the worker through the task at hand, as tasks can be hard to accomplish due to physical limitations of the hardware used and the environment in which the work is being performed. We have evaluated the tool in an industrial setting where we have set up a simple test case with recognizing numbering on connectors in workshop-like setting. Through this evaluation we have identified that using a guidance tool which processes the view and extracts desired data onto a mobile device increases the speed at which the task is being performed and as such it decreases the complexity of the task. In addition, the evaluation participants have brought up some concerns regarding the tool and additional functionality which could expand the tool's applicability. While the evaluated prototype contained only minimal functionality, we believe we have set a solid groundwork to encourage further research on the topic of application of the AR technology within the automotive industry.

A. Future Work

The presented research work could be expanded, since it covered only the most basic application of a helper tool within industrial context. The artefact could be improved with more functionality to evaluate the effects helper tools could bring to a wide variety of workshop tasks. As the interviewees have identified, scaling up the functionality of the tool to identify more objects, such as harnesses and ECUs, would be beneficial as it would help lower the amount of paper instructions being used. This is desirable for future work as it would bring a more general view on the state of art. In addition, to validate the study, future studies should aim to include a bigger sample in the research, as physical abilities and levels of experience of individuals can greatly influence the result of the research in this area. This would provide more evidence as to how helper tools could help solve physically demanding workshop tasks.

Acknowledgment

The author would like to thank our industrial supervisor Henrik Fagrell at the partner company, Diadrom, who initiated this project, and our academic supervisor Federico Giaimo, for his availability, guidance and support. The author would also like to thank our examiner Christian Berger for valuable feedback that helped develop the work.

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Appendix

A. Interview Questions

1) Which are the top three challenges you face when working with connectors and pin-outs identification?
2) How would/could a hand-held device affect your work?
3) How could a mobile phone be used in a workshop environment to ease tasks such as verifying the connector works,for which we need to know pin-outs to connect it correctly?
4) Are you familiar with the concept of Augmented Reality?
5) Have you used an AR application before?
6) How do you think an AR application could help you in your tasks/work.
7) What functions would you desire the app to have in order to better help you with pin-out identification tasks? (If multiple are mentioned, we ask for top 3.)