DESIGNING AUGMENTED REALITY INTERFACES FOR HUMAN-ROBOT COLLABORATION IN ENGINE ASSEMBLY

RESEARCH PROPOSAL

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ABSTRACT

Customers are becoming more and more individualistic, products are getting more variation and the global market drives for shorter lifecycles for products. The industry is introducing more robots but even though they become more flexible there is still a need for human workers. Fenceless robots and new standards in robotics have made it possible for humans and robots to directly collaborate, allowing them to complement each other with their respective strengths. But how can humans keep up with the increased need for learning new products while collaborating with robots?

Studies in using Augmented Reality (AR) show that it might help workers to perform complex operations more efficiently.AR can spatially orient information and thereby present it in context to reality. But AR in actual industrial assembly is still in its infancy, there is a lack of general AR implementations as most AR is done for specific cases and there is still little knowledge about how to generally design AR-based interfaces efficiently.

This project aims to explore how AR is most efficiently used in industrial engine assembly. It focuses on cases with Human-Robot Collaboration since the current trend is clear that this will be very common in the future. The goal is to find basic design guidelines for how to best present information to workers; when to present it, what to present and how to present it.

Industry representatives will help in creating an evaluation-framework that is relevant for real situations. The guidelines will be iteratively evaluated with this evaluation-framework and designed through the methodology of design science. The goal of this research project is to contribute with a framework for how to evaluate AR-based operator instructions and design guidelines that creates generally more efficient instructions for operators.

Keywords: Augmented Reality; Operator support; Assembly

CONTENTS

1 INTRODUCTION

Customers are becoming more and more individualistic, products are getting more variation and the global market drives for shorter lifecycles for products [1-4]. This puts a demand on the industry to deliver more variants on their products and to introduce new products more often. Robotics are becoming more flexible but are currently not flexible enough to cost-effectively replace all human workers [5]. A limitation that currently exists for a large part of robotics implementations are safety-concerns for humans [6]. Robots have traditionally needed large areas to work to allow for safety precautions such as safety-fences [7] but are currently being taken out of the fences to interact with human workers.

If robots can become safe enough for humans to efficiently interact with them in the manufacturing industry there are great advantages to be had with the flexibility, precision and quality skills of humans and the endurance and strength of robots [8]. Robots can now work in collaboration with humans and currently there is a lot of research into making robot interaction more dynamic and efficient without creating risks for humans. [9, 10]

The aforementioned demands from the market combined with future collaborative robotics means that future human operators are likely to face an increase in product variation, shorter life-cycles of products (and thereby more relearning) and collaboration with robots. This puts an increased demand on workers to learn more operations simultaneously and to learn new products more often. How can this be achieved without reducing quality and efficiency?

Augmented Reality (AR) makes it possible to present virtual information in a direct connection with objects in the real world [11]. As a result there has been many studies on how to use AR to present assembly instructions that has shown positive results [12].

1.1 PROBLEM DESCRIPTION

Augmented Reality (AR) is a technology that allows for contextualizing information to the physical reality and thereby reducing the need of spatial interpretations for the operator, for instance to interpret 2D-schematics and cognitively transfer this information into a 3D-reality. Previous studies support that AR-based instructions can make assembly more efficient [13]. There is however some critique against this view since there are no benchmarks for evaluating AR efficiency [12]. Despite this critique it is a reasonable assumption that AR can be an effective tool for assembly guidance and it’s also an area in need of further research [14]. Another area that’s in need of further research is regarding design guidelines for AR-based instructions in assembly [12].

1.2 AIM AND OBJECTIVES

This project aims to explore how AR interfaces for HRC in engine assembly should be designed for gaining the maximum benefit of AR. The project is divided into three major parts:

1. The first part of the work will be to develop new methods for evaluating the efficiency of AR-based instructions. These methods will be the foundation of the thesis and will be used throughout the project for evaluating different solutions developed.
2. The second part of the work will be to develop general guidelines for how to best present information using AR-technology. The guidelines aim to results in better ways of guiding the operators through their tasks.
3. The third part of the work will be to develop recommendations on which AR-hardware-platform(s) to use in different scenarios and how to apply the guidelines developed in the previous step for the different platforms.

This project aims to make the following contributions:

- Develop new methods of evaluating the efficiency of AR-based instructions.
  - The methods will be able to evaluate in comparison with currently used instructions such as paper-based schematics.
  - It will also be able to evaluate in comparison between different AR-based instructions.
- Develop general guidelines for how to efficiently design AR-based instructions.
- Evaluate the strengths and weaknesses of different AR-hardware-platforms.

To reach these contribution-goals a set of research-objectives are defined. These are:

1. Develop a framework for how to evaluate the efficiency of AR-based instructions in industrial engine assembly HRC.
2. Identify what information is needed in AR-based instructions for a human operator to complete industrial engine assembly HRC.
3. Investigate how graphical design and placement of information from objective 2 affects efficiency in regards to objective 1 in industrial engine assembly HRC.
4. Evaluate suitability of different AR-hardware-platforms in regards to understandability, user-comfort, technological maturity and safety in industrial engine assembly HRC.

1.3 SCOPE AND LIMITATIONS

This project will focus its research on engine assembly manufacturing performed with Human-Robot Collaboration (HRC). There are many reasons behind limiting the work to engine assembly manufacturing. Firstly there is a global environmental awareness that has put high demands on the industry to improve engine efficiency[15]. These demands are likely to increase the amount of changes to engines and thereby increase the need for relearning among operators. Engines are suitable for HRC since they are composed of many different components from heavy castings that robots can handle with ease to small screws and materials that are complex to handle and assemble such as rubber isolation that are more suitable for humans. The Volvo Cars Corporation's involvement in this research project also show that there is an interest from the corporate world in this kind of research. It is also in part motivated by scope and practical reasons such as availability of potential testers. And the reason behind limiting the work to HRC is scope but also because it is believed that future industrial assembly will have a high amount of HRC in general. Robots used within this project will be limited to robots that are certified for HRC. This is mainly motivated from a safety perspective but also in regards of scope and availability.

The basis of how instructions will be presented in this project will be an AR-based interface. This is motivated by scope and by the possible potential of AR that has been observed [12-14]. But the interface will not be strictly restricted to only AR-elements. A text-instruction that has a fixed screen-space position doesn’t fulfill the definition of combining real and virtual objects and aligning them with each other [16], but to limit an AR-interface to not include similar elements is not seen as a goal in itself here.

1.4 STRUCTURE OF REPORT

Section 2 describes the theoretical background of this research project including the gaps it plans to fill. Section 3 describes the overall plan of the project including methodology, time plan, publication plan and expected results.

2 BACKGROUND AND PURPOSE

In this section the backgrounds and state of the art about Augmented Reality (AR), assembly and the application of AR in Human-Robot Collaboration (HRC) for industrial engine assembly are reviewed. The gaps between the industrial requirements and the current solutions emerge from these detailed reviews so that the purposes of this research are described clearly and accurately.

2.1 THEORY

2.1.1 AUGMENTED REALITY

The first usage of the term AR was in 1992 to describe how the visual field of the user was augmented by technology with information necessary to perform their current task [17]. AR was later defined to have the following three characteristics: To combine real and virtual objects, in real time and interactive and finally that this combination is registered in 3D [11]. The definition was not limited to specific technological implementations of AR and in a follow up study AR was widened to include more senses than the visual: *"AR can potentially apply to all senses, including hearing, touch and smell."* [16[p.34]]. Within this research project only visual AR will be considered. Even though these sources are up to 19 years old this definition is still widely adopted and cited within the field of AR.

2.1.2 ASSEMBLY

To be able to evaluate the efficiency of AR-based instructions in assembly it is important to know what assembly is. Assembly is defined as:

"The aggregation of all processes by which various parts and subassemblies are built together to form a complete, geometrically designed assembly or product (such as a machine or an electronic circuit) either by an individual, batch or a continuous process." [18[p. 2]]

Assembly consists of assembly tasks which are defined as:

*"**Assembly tasks** include two basic categories: **parts mating** and **parts joining**. In parts mating two (or more) parts are brought into contact or alignment with each other. Parts joining mean that after parts are mated, fastening is applied to hold them together. Mating tasks include: (1) peg in hole, (2) hole on peg, (3) multiple peg in hole and (4) stacking. Joining or fastening tasks involve: (1) fastening screws, (2) retainers, (3) press fits, (4) snap fits, (5) welding and related metal-based joining methods, (6) adhesives, (7) crimpings and (8) riveting." [18[p. 23-24]]*

The aforementioned definitions of assembly describes all types of assembly. In this research project only industrial assembly, which requires high efficiency, is included. It is also important to be able to assess assembly complexity to allow for comparison of different assembly setups. This paper [4] describes criteria for assessment of basic manual assembly complexity. The relative values of the criteria are not currently known however.

2.2 RELATED WORK

AR for usage in industrial assembly has been a research area for over two decades [12]. AR systems are seen as promising training platforms for complex and highly demanding industrial maintenance and assembly tasks and shows promising results in experiments [14]. HRC has been successfully introduced in the manufacturing industry but the collaborative elements are still limited and most of the robots are lightweight [19]. There is still however a lack of approaches of AR in combination with HRC outside laboratory environments even though AR can be useful in HRC to enhance safety awareness and efficiency [20]. In an attempt to create a classification to facilitate interface design of AR assembly assistance this paper tested the effect of how instructions are formed based on the difficulty of the tasks [21]. Although their results didn't support their hypothesis, observations and partial results indicate that task difficulty can be important.

2.3 PURPOSE

AR within assembly research has been researched for over 25 years, but the design of prototypes have in large lacked general design guidelines [12]. This project hopes to contribute with general rules for how AR-elements should be graphically designed and placed within the field of view of the user to give an optimal cognitive understanding in as short a time as possible. HRC is also an increasing trend within the manufacturing industry and therefore these guidelines will also consider how to best facilitate HRC in an engine assembly environment. By taking HRC into consideration in the guidelines they are more likely to be of use in HRC. The planned evaluation framework will enable consistent evaluation both between different guideline iterations in this project and in other projects, thereby providing a general way of comparing different guidelines.

3 THE PLAN OF WORK

This section describes the work that is planned for this research project. These are methodology, research strategy, overall time plan, publication plan and what results that are expected after completing this project.

3.1 METHODOLOGY

3.1.1 DESIGN SCIENCE

The methodology chosen for this research project is design science. March & Smith summarizes design science in the following way: *"Natural science aims at understanding and explaining phenomena; design sciences aims at developing ways to achieve human goals."* [22[p. 254]] Design science focuses on the creation of artifacts to help further knowledge. It uses practical implementation to find more effective ways of doing things.

According to March & Smith [22], the products of design science can be one of the following: constructs, models, methods and implementations. They define constructs as the basic concepts needed to characterize phenomena. Models uses a combination of constructs to describe tasks, situations or artifacts. Methods are the ways to perform activities which can be used to create specific implementations to achieve the goals.

"Design science consists of two basic activities, build and evaluate."[22[p. 254]] *"Building is the process of constructing an artifact for a specific purpose; evaluation is the process of determining how well the artifact performs."*[22[p. 254]]

Design science aims to solve practical problems by creating artifacts. Because of this a common critique against design science is that design takes place all the time without it being called science; Therefore it is important that design choices are well motivated and evaluated before and after they are made [23]. The artifacts and the process of creating them is science since this process generates new knowledge.

3.1.2 APPLICABILITY ON THE PROJECT

Hevner et. al establishes seven guidelines for effective design science research [24]. They do not advocate strict adherence to the guidelines but rather that they should form a basis for determining if something is good design science research. This section shortly describes these guidelines and accounts for how they apply to this research project.

Guideline 1 is Design as an Artifact. Design science creates artifacts to address relevant problems. The design process is shown to be feasible through the artifact. And the creation serves as a proof that it can be done and provide a way to change how tasks and problems are conceived. The goal of this research project is to develop an evaluation method and design guidelines. This will be accomplished by iteratively designing artifacts following iterations of the guidelines and evaluated with the evaluation method. The hypotheses is that these artifacts will show that the guidelines are feasible by following them and that the evaluation method will show an improvement. Therefore this research project follows guideline 1.

Guideline 2 is Problem Relevance. If a problem is not relevant, that is if the result from solving the problem doesn't lead to a better situation in any real application it has no value of being solved. This research project aims to make engine assembly more efficient by providing design guidance in how to present information effectively and a way to evaluate the efficiency. As has been argued in the first section of this report, this is an area in need of continual improvements and there is a lack of knowledge within this application-field. Therefore this research project follows guideline 2.

Guideline 3 is Design Evaluation. Since design science focuses on practical improvements to real problems this must be evaluated to show that there has been an actual improvement. How this is measured varies with what is relevant within each application field but it should be both relevant and comparable. A problem for this research project, which has been mentioned in section 1.1, is that there are no standards for how to evaluate guidelines for interfaces of this kind. This is why this research project aims to create a method for evaluating these forms of guidelines if possible. If this research project reaches this goal it will follow guideline 3.

Guideline 4 is Research Contributions. This boils down to the trivially true fact that all research must create new knowledge. Design science can contribute through the design artifact if it solves unsolved problems or solves old problems in new areas. It can also contribute by developing new constructs, models or instantiations. And finally it can contribute through creating new evaluation methods and new evaluation metrics. The aim for this research project is to contribute with two contributions to general knowledge. First by providing a way to evaluate AR interfaces and later by creating new guidelines for how to design these. If this research project reaches these goals it will follow guideline 4.

Guideline 5 is Research Rigor. This addresses how the research is done, the replicability of the process, assumptions made and similar. Design science should balance the need for simplification to make quantifiable measurements/calculations with the need for relevance in reality. This research project will attempt to maintain this balance through involving representatives from the Volvo Cars engine plant to ensure there is a relevance to real problems they face. But it will also base design decisions on known theory and document the design process to ensure replicability. If this research project reaches these goals it will follow guideline 5.

Guideline 6 is Design as a Search Process. Real business problems are usually too complex to allow an exhaustive search of solutions. Therefore the goal of design science is not to find the best solution but to find a better solution than currently available. This is done iteratively by a cycle of generating design alternatives and then testing them against requirements/constraints. This research project will define requirements in collaboration with representatives from the practical field and then iteratively search for guidelines that leads to better results. Therefore this research project follows guideline 6.

Guideline 7 is Communication of Research. This addresses presenting information about the research in a format adapted so the target audience can understand its content. Those with a focus on technology should be able to implement the results and those with a focus on management should be able to decide the strategic value of implementing the results. This research project has so far had dialogues with industrial representatives discussing the strategic value of this research and this is planned to continue throughout the project. The design process will be documented to show the gradual changes which will enable academic and technical replicability. If this research project can maintain this setup it will follow guideline 7.

To summarize, this research project is assessed to certainly follow three of the guidelines (1, 2 and 6) and to follow four of them if all goes to plan (3, 4, 5 and 7). Design science is therefore seen as a suitable methodology.

3.1.3 Evaluation

As has been mentioned in chapter 1.2, the general design guidelines that this project aims to create will be evaluated by developing a framework for how to evaluate them. The framework will be developed in collaboration with industrial representatives to ensure a practical value of the evaluation attributes. It will also be based in established theory.

The general design guidelines will be evaluated by following them to create GUI-systems. These GUI-systems will then be tested in user-tests to assert effectiveness. User-tests are chosen since the main goal is to find ways to make operators more effective. Each generation of guideline – GUI-system will give information after user-tests about where to improve on the guidelines and thus refine the guidelines. A common critique against design science is that it is simply development. It is therefore important both to be able to handle this form of critique but also to take action to ensure that the research will not fall into the trap of becoming just development. Each iteration of the guidelines will be documented and the changes motivated before testing them. The changes will be formulated into hypothesizes to be specifically evaluated in the user-tests to ensure a structured and reproducible result.

3.1.4 Ethical considerations

The ethical considerations that has been and will be made in this project are based on the recommendations from the Swedish Research Council [25]. Many user-tests will be performed during this research project. It is therefore important to ensure that written and informed consent is gathered from all research participants. Information to research participants will include information about the purpose of the experiment, their role, the expected results and how results are aimed to be used. There will be some limitations to what is said before experiments so as to not affect the results. Experiments will include HRC and even though robots used will be certified for HRC there might still be a need for extra precautions in some experiments depending on how the HRC is designed. The potential risk towards research participants are estimated to be small enough to not warrant an evaluation in accordance to legislation [26].

3.2 RESEARCH PLAN

The research plan for this project is summarized in table 1 and covers all major important events for the project. The years in table 1 start at September which is the starting month for this research project. The planning shows a rough distribution of time budgeted for each task. Red and blue boxed arrows shows deadlines for the PhD-program and the IPSI industrial research school respectively.

The courses, marked purple in the table, are planned to be finished by the middle of 2017. This is because this gives the theoretical knowledge provided by the courses early, gives more focused time later in the project for the research and it gives time to adjust if particular courses are cancelled. The early focus on courses means there is less time initially for research which is compensated by it having more focus in the later part of the project.

The EU-project SYMBIO-TIC looks into human-robot collaboration. Some parts of this project offer a good opportunity for this research project since it will develop demonstrators which shows HRC in the context of assembly. The deadlines of the research questions and experiments have been adjusted with those in the SYMBIO-TIC project to be able to use synergy-effects.

TABLE 1: COMPLETE RESEARCH PLAN FOR THE PHD PROJECT.

	sep	okt	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
Year		IT920F					IT708A					PE-
1			IT706A					IT923		Vacation	Thesis: RP	
	ISP											
2015 -				SYMBIO-TIC: D 4.2				VG	Literature			
2016							Institution-service					
	sep	okt	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
Year	-814A			PE818A		PE819A		PE820A				
2	CG				FPRF010			Course: Dev ind.p				
		RQ1: Develop				RQ2: Creation				Vacation	RQ2 Experiments	
2016 -	RP						Literature					
2017							Institution-service					
	sep	okt	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
Year				Thesis: write-up				DG			Publish: paper	
3							Literature	TP				
		RQ3: Creation				RQ3: Experiments				Vacation		RQ4:
2017 -					SYMBIO-TIC: Test-bed preparation							Publish:
2018							Institution-service					
	sep	okt	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
Year		journal					Publish: journal					
4							Literature					
	Creation			RQ4: Experiments					Thesis: write-up	Vacation		
2018 -			SYMBIO-TIC: Demonstrator 3				SYMBIO-TIC: Report					
2019							Institution-service					
	sep	okt	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
Year												
5					Literature					TG		
					Thesis: final write-up						Thesis defence	
2019 -												
2020							Institution-service					

Courses		Publications	
Research questions		Institution	
Literature		External	
Writing		Unscheduled	

There are four research-objectives that need to be fulfilled in order to achieve the overall aim of the project:

- Objective 1, AR-efficiency framework, is the first objective that forms the basis for the following objectives. Three months of part-time is set aside for this.
- Objective 2, general elements in AR-assembly, will require five months of part-time work to set up experiments to test which elements are needed for assembly and three months to test.
- Objective 3, graphical design and placement of AR, is the final objective and will base its work on the previous objectives. Three months of part-time work is planned for this objective and five months for testing. This objective is synchronized with an assembly demonstrator that will be developed in the SYMBIO-TIC project so that this objective can utilize this demonstrator.
- Objective 4, AR-platform suitability, is set to start in the third year. This is in part because head-mounted displays are still in general a bit bulky for pro-longed use but in two years it is likely to have become better since there is much development within this field, for instance Microsoft Hololens [27] and Meta 2 [28]. This objective will build on the previous two objectives and will require five months of part-time work and three months for testing.

There are three main deadlines in this project which follows the general study plan of the University of Skövde. These are research proposal (this document), thesis proposal and final thesis [29].

- This document finalizes the research proposal, due in August 2016.
- The thesis proposal is planned to be finished by April 2018. This document should contain some early results from this project. Therefore September 2017 – March 2018 is planned for this report. It will not take full-time however.
- The final thesis is the final report of this entire research project. As such it will be the main focus from September 2019 – May 2020.

The project is planned for five years in total. It started in September 2015 and is planned to be finished by September 2020.

3.3 COURSE INTEGRATION AND PUBLICATION PLAN

This research project has two goals, to add to the collective body of knowledge within the area of designing for AR in HRC assembly and to educate me into becoming a PhD. In consideration to this, courses are included in this project to further enhance my skills within the related fields.

TABLE 2: COURSE SUMMARY

Course(s)	Purpose
Scientific Theory in Informatics	Mandatory course that teaches the scientific method and the different theories within the domain of informatics.
Scientific Methodology and Communication for Informatics	Mandatory course that teaches how to analyze and produce research through the use of specific methodologies.
Scientific Seminar in Informatics I-II	Mandatory courses that teaches recent findings in Informatics and how to present research results to an audience.
Project Management for PhD students	This course teaches how to administer research projects and PhD studies, thus increasing general productiveness.
Communication and dissemination of research using demonstrators	This course teaches how to present proof of concept of research and gives an opportunity to create a first iteration of a test-bed for future experiments.
Future production	This course teaches the state of the art in production technology and methods to foresee changes and shifts in technology.
Development of industrial production systems	This course teaches the possibilities and limitations of development in an industrial setting.
Teaching and Learning in Higher Education 1-4	These courses teaches theories and strategies for teaching in higher education. It's primary of value in my future duties as an academic to teach but will also give me tools to teach in other situations.

Publication channels have been chosen from the lists known as the Danish list, Finish list and Norwegian list. When SwePub has been accepted by the University of Skövde this publication plan will be revised to harmonize with potential changes [30]. The publication channels have been matched to the objective as well as they have a progression of rank to accommodate for the increasing experience as the research project advances.

TABLE 3: PUBLICATION PLAN.

Activity	**Publications**	**Rank [30]**
Research proposal	DIVA	
Objective 1 – AR-efficiency framework	Swedish Production Symposium	0
Objective 2 – general elements in AR-assembly	IEEE Transactions on Industrial Informatics	1
Thesis proposal	DIVA	
Objective 3 – graphical design and placement of AR	Journal of Usability Studies	1
Objective 4 –AR-platform suitability	Journal of the ACM	2
Final thesis	DIVA	

3.4 EXPECTED RESULTS

The expectation is that a generally usable evaluation-system will be developed. Also that general guidelines about how information should be designed for operators to work with robots in industrial engine assembling efficiently are created. The guidelines will instruct how to design AR interface.

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