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Assessing Instructions in Augmented Reality for Human-Robot Collaborative Assembly by Using Demonstrators

Oscar Danielsson[a]*, Anna Syberfeldt[a], Rodney Brewster[b], Lihui Wang[c]

[a]*University of Skövde, Kanikegränd 3A, Skövde 541 34, Sweden*
[b]*Volvo Car Corporation, Komponentvägen 2, Skövde 541 36, Sweden*
[c]*KTH Royal Institute of Technology, Kungliga Tekniska högskolan, Stockholm 100 44, Sweden*

* Corresponding author. Tel.: +46-500-448-596; fax: +46-500-416-325. *E-mail address:* oscar.danielsson@his.se

Abstract

Robots are becoming more adaptive and aware of their surroundings. This has opened up the research area of tight human-robot collaboration, where humans and robots work directly interconnected rather than in separate cells. The manufacturing industry is in constant need of developing new products. This means that operators are in constant need of learning new ways of manufacturing. If instructions to operators and interaction between operators and robots can be virtualized this has the potential of being more modifiable and available to the operators. Augmented Reality has previously shown to be effective in giving operators instructions in assembly, but there are still knowledge gaps regarding evaluation and general design guidelines. This paper has two aims. Firstly it aims to assess if demonstrators can be used to simulate human-robot collaboration. Secondly it aims to assess if Augmented Reality-based interfaces can be used to guide test-persons through a previously unknown assembly procedure. The long-term goal of the demonstrator is to function as a test-module for how to efficiently instruct operators collaborating with a robot. Pilot-tests have shown that Augmented Reality instructions can give enough information for untrained workers to perform simple assembly-tasks where parts of the steps are done with direct collaboration with a robot. Misunderstandings of the instructions from the test-persons led to multiple errors during assembly so future research is needed in how to efficiently design instructions.

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1. Introduction

1.1. Current industrial challenges

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. Robots 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 is 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 robots 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

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on workers to learn more operations simultaneously and learn new products more often. How can this be achieved without reducing quality and efficiency? This paper has two aims. Firstly it aims to assess if demonstrators can be used to simulate human-robot collaboration. Secondly it aims to assess if Augmented Reality-based interfaces can be used to guide test-persons through a previously unknown assembly procedure.

1.2. Augmented Reality

Augmented Reality (AR) makes it possible to present virtual information in a direct connection with objects in the real world [11]. AR works by connecting the real world with the virtual, for instance with specific patterns that are pre-known. When a camera captures and digitalizes what is seen in front of it software can recognize the pattern and it can use the information of where the pattern was recognized to superimpose digital information on top of the rendering from the camera, thereby creating a mix between virtual and real information. This means that AR can show digital information in a real setting and in a specific context, for instance by highlighting real objects. As a result there have been many studies on how to use AR to present assembly instructions that has shown positive results [12]. But although there are positive results there is still more studies needed regarding how the instructions should be presented and how to comparatively evaluate them [12].

2. Demonstrator

2.1. Demonstrator as test-bed

To our knowledge there is no factory that currently have implemented Human-Robot Collaboration combined with Augmented Reality in production. A demonstrator was therefore created where a person will collaborate with a Human-Robot Collaborative robot, a UR3 robot from Universal Robots. A simplified car-model that can be assembled and dis-assembled by hand was developed and can be seen in Fig. 1.

The greatest advantages of using a demonstrator in user-tests are the authenticity and the modularity. The demonstrator allows a test-person to interact directly with a real HRC-robot in an assembly-scenario and thereby simulates a real situation. It is not as believable as real industrial assembly but it does not need to disrupt any real industrial assembly either. The currently developed demonstrator is limited to one test-person and one workstation and is thereby limited in comparison to industrial assembly that is mostly done with close connectivity between workstations and operators. Since the demonstrator is fully developed for experimentation it is also modular and can be changed depending on what needs to be tested. Together these two advantages means that the demonstrator can put a test-person in a semi-authentic situation and, depending on complexity of needed modifications, it can also be modified depending on findings within minutes or hours.

In the first iteration, the car-model was created with wood and the pieces were held together with friction between the pieces. A drawback with this model was that test-persons only had to identify, orient and position the individual parts; there was no need to fasten any pieces with anything else but friction. To make the car-model similar to more generic assembly, a new model was created. The pieces were 3D-printed which allowed for more detailed parts to be created. The new car-model had increased complexity in that thumbscrews were now needed to fasten some parts.

Fig. 1 First iteration of demonstrator.

2.2. Augmented Reality Interface

To present the instructions for the test-persons a spatial top-view Augmented Reality system was created. The platform for the system was the game-engine Unity-3D. In the first iteration AR was implemented with the help of the Vuforia AR-system for Unity. The AR-system was built for Android and launched on an Nvidia Shield Tablet that can be seen at the top of Fig. 1. This tablet was chosen since it has both a USB-connection and mini-HDMI connection which was necessary to both have communication between the AR-system and the Robot Control system and to be able to project the visual information on a screen for the test-person to see. Test-persons worked with the table seen in Fig. 1 in front of them. This set-up meant that they had the work area in front of them, pieces to assemble at their sides, a screen giving the test-persons AR-instructions and a UR3 robot to their left that they had to collaborate with to assemble the car.

2.3. Second iteration of interface

Two big drawbacks with the chosen version of the AR-system was the low battery-life of a tablet that has to continuously have an active camera and the mixing of two platforms. The tablet runs on Android and the Robot Control System runs on Windows and communicates with TCP via USB. We therefore made a second iteration where the Vuforia AR-system was replaced with ARToolKit, which supports the Windows-platform.

The AR-tracking was using the inbuilt multimarker functionality of ARToolKit with 6 markers. There was a redundancy in the number of markers to allow test-persons and the robot to move freely in-between the camera and the markers.

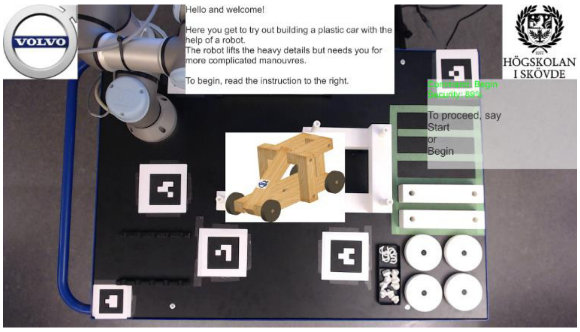

Fig. 2 Introduction screen of AR interface.

The interface was designed to guide the test-person with a combination of textual information and AR to highlight parts of specific interest in each step. Fig. 2 shows what the test-person would see on the screen in front of them when beginning their test. The text in the middle explain in general terms what they are to do. To the right they can see voice-commands that the system currently accepts. The interface needed a voice-recognition-security of at least 85 % in order to avoid false positives. Values between 60 % and 100 % were shown to the test-person, values between 60 % and 85 % were shown in red to indicate that the system had detected a possible command but was not sure enough. Values above 85 %, in Fig. 2 the value is 89 %, were shown in green to indicate a correctly recognized command.

Once the test-person gave a start-command the interface would remove the introduction text and present all textual information in the upper right corner of the screen so as to not cover the areas of the screen where the test-person would work. An example of the interface during assembly is seen in Fig. 3. The top part of the text-area contained specific instructions for the test-person on what they were to do. Just below this the test-person could see their overall progress through the construction. Below this recognized and available voice-commands would be seen as previously explained in connection to Fig. 2.

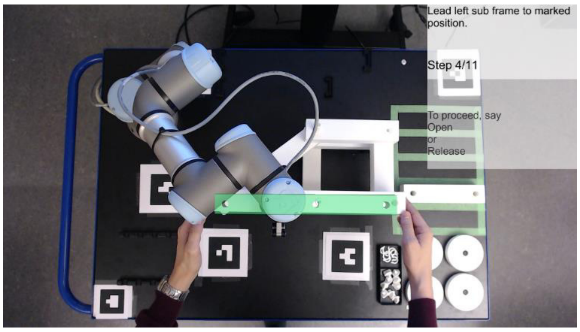

Fig. 3 Step four, where test-person and robot collaborate.

2.4. The car-assembly

In the first iteration of the demonstrator, the test-persons had to assemble the entire car. For the second iteration, we changed this so that the test-person only had to assemble parts of the car. The three reasons for this were that we had introduced more complex parts to assemble and did not want to increase overall effort for test-persons, that not all parts were of interest seen to Human-Robot Collaboration, and a minor reason was also that the most common situation is that assembly workers only build part of a product.

The second iteration had a total of 11 steps for a test-person to perform and is presented in Table 1. The level of Human-Robot Collaboration (HRC) is defined as direct, indirect or no HRC. Direct means there is direct interaction between the test-person and the robot, in these cases haptic control of the robot. Indirect means that the robot or human support each other but have no direct interaction, in these cases the robot holds the assembled car in a fixed position to ease assembly.

Table 1 Car-assembly steps

Text-instructions	HRC
Lead front and position according to marking.	Direct
Lift the robot-arm ca 1 decimeter.	Direct
Take left roof and fasten between front and back.	No
Lead left sub frame to marked position.	Direct
Lift the robot-arm ca 1 decimeter.	Direct
Take left door and fasten at marking.	No
Take two lock-rings and assemble one at each protruding assembly-pin.	No
Take two wheels and tread on the protruding assembly-pins.	No
Take five thumbscrews and assemble one at each assembly-pin.	No
Take two wheels and tread on the protruding assembly-pins.	Indirect
Take two thumbscrews and assemble at the wheels.	Indirect

3. Methodology

3.1. Tested software

A pilot-study was performed for the second iteration of the interface to test how intuitive the interface was for new test-persons. The main goals were to see if the assembly was complex enough to require instructions to finish and that the assembly was feasible to finish for a test-person without previous instructions. This was to evaluate whether the demonstrator needed any major revisions before more in-depth user tests.

To compare how different designs of the interface affect test-persons, two versions of the AR-interface was implemented. Both versions were identical apart from that in one version the parts where the test-person should initiate actions were blinking and in the other version they were not blinking.

As explained in section 2.3, the test-persons interacted with the interface with the help of voice-commands. In each step they could issue two voice-commands that both did the same thing. This was to allow an alternative if the test-person had problems to pronounce the command clear enough for the software to recognize. There were two different versions of the voice-commands. One word-versions, for instance "start/begin" and multiple word-versions, for instance "start demonstrator/begin building car". All four possible combinations were connected and set up for the user-study. Program 1 had blinking and short commands, program 2 had no blinking and short commands, program 3 had blinking and long commands, and program 4 had no blinking and long commands.

3.2. Test-group, environment and test-layout

Four groups of high-school students from local technical schools were used as test-groups. The students were chosen since they are very likely to have a career within the manufacturing industry. This makes them representative of parts of the future workforce within the manufacturing industry and their attitude towards this solution is valuable in the context of future workforce employment. The ages were self-reported in the interval 15-17. Genders were also self-reported and are presented in table 2.

Table 2 Group composition

Group	Program	Females	Males	Others	Total
1	1	7	17	1	25
2	2	7	19	1	27
3	2	7	18	0	25
4	3	4	14	3	21

Each group partook separately from each other. In each group 3 volunteers were chosen to perform the assembly. Table 2 shows which group had which program and shows that group 3 mistakenly got the same program as group 2. Of those chosen to perform the assembly, one stayed in the room and used the demonstrator while the other two left the room to avoid learning-effects. The room layout was a lecture classroom with a pitched floor and it was well lit during the tests. The students were seated in the front three rows of the auditory and the demonstrator was placed on the floor in front of them.

After the first test-person had performed the assembly it was led aside to a table to fill out a usability-questionnaire. Then the next test-person was brought in to perform the assembly and the observing students were given questionnaires. After the second test-person was finished it was also led to the table to fill out a usability-questionnaire and the third test-person was led in. Finally the third test-person was also led to the table to fill out the same usability-questionnaire as the other two.

During each assembly one test-assistant noted times the test-person asked for help and when they did not do as instructed by the AR-interface. The language used for the entire study was Swedish.

3.3. Questionnaire-design

Both questionnaires used a five-level Likert-scale. The test-persons filled in 10 questions regarding the interface and the questions were based on the SUS-test [13] but translated to Swedish. The observing students filled in a questionnaire with 6 questions regarding general interest and 5 questions regarding the information displayed on the screen for the test-person.

3.4. Error-sources

The students chosen for performing the assembly were those who raised their hands first when we asked for volunteers and are therefore likely to have a positive bias for trying new technology. While the groups were mixed, volunteers were all male. The remaining students observed the test-persons and could interact with them even though this was discouraged and thus influenced the test-persons behavior. Program 4 was not tested due to a miss during execution of the test.

We did not manage to create a perfect alignment between the virtual and real world, which could have reduced understand-ability with the test-persons. The questionnaire for the test-persons was translated from English to Swedish, which can have affected the outcome.

4. Preliminary results

The first iteration was primarily used as a proof of concept that the demonstrator was feasible and the general layout understandable by test-persons. It was tested with volunteers at two different exhibitions. The tests indicated that the system was intuitive enough and on a difficulty level that allowed for most of those testing to be able to complete the task. For this reason there was no major revision of the setup from the first to the second iteration of the demonstrator.

The first iteration was also specifically presented for industrial representatives from the car-manufacturing industry to assess future industrial relevance. The response we received was that the concept was seen as relevant seen to industrial challenges in the near future.

The data from the user-study is inconclusive. The SUS-scores of the groups were 80.8, 75, 32.5 and 77.5. Due to all the possible error-sources, there can be many different reasons for the different outcomes between group 3 and the other three groups. Group 1, 2 and 4 followed the same trend in the SUS when broken down to individual questions as can be seen in Fig. 4.

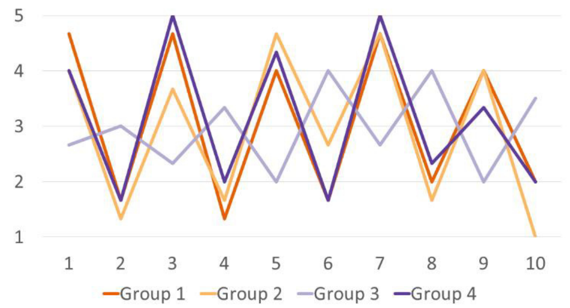

Fig. 4 Average SUS-score per question

A summary from the test-protocol shows that of the 12 test-persons, all of them made errors in at least one of the steps. Of the total of 144 assembly steps, 75 steps were performed with at least one deviation from the given instructions. In open discussions after the tests many of the test-persons and students from the observing group pointed out that it was unclear that they should read the instructions in the upper right corner.

5. Summary

5.1. Conclusions

This paper has two aims: to assess if demonstrators can simulate human-robot collaboration and to assess if AR-based interfaces can guide test-persons through assembly.

Regarding the first aim, the paper has shown that demonstrators can be used to create a modular test-environment that allows a test-person to perform real assembly in collaboration with a robot. The results from the pilot-study were distorted since the test-persons had their peers behind them when working. Despite this they managed to go through all the steps of the instructions. Based on this it can be said that the demonstrator has reached a level of maturity that enable persons without prior assembly-experience to independently work through all the steps of the demonstrator. This answers the second aim of this paper. But the amount of errors when working independently is far too high to be acceptable. The amount of errors shows that the assembly is complex enough to require instructions. Therefore the task in the demonstrator is of a satisfying complexity but the instructions need to be clearer. The screen shows a top-view of the assembly-area and is thus limited in how instructions can be shown.

While the current results have not given specific insight in how different designs affect the performance of test-persons it has given validity to the method of using demonstrators to test assembly-instructions. Further validity of the method was given from the feedback from the industrial representatives.

5.2. Future work

The demonstrator will be tested in more in depth user tests. Future tests will also be performed in a more controlled environment to reduce error-sources. Test-persons will work alone and be recorded to allow for more detailed observation of types of errors and where they focus when they work. The demonstrator itself will also need revision and future work for it includes:

- Increasing Augmented Reality tracking accuracy.
- Changing or adding camera-angles from which the assembly area is displayed in the interface.
- Layout of the different parts of the interface needs to be revised and also how the different parts are presented to ensure that test-persons find them.
- The information design will be updated.
- Increased system functionality such as animation to provide opportunities to use the strengths of AR-technology more effectively.

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