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Augmented Reality Efficiency in Manufacturing Industry: A Case Study

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Abstract

Human workers are flexible and able to solve problems; hence, their significance in the complex assembly work is important even today. The challenge is to deliver relevant assembly information to the workers about each task at a given time. Augmented Reality (AR) provides new opportunities to enhance assembly work.

The rapid development of small-sized low-cost technology such as handheld computers, head-mounted displays and camera phones with enough processing capacity and long lasting batteries has enabled light-weight mobile AR systems.

In this study, the usability of augmented reality in assembly is tested by our industrial pilot case that focuses on the assembly of a tractor accessory's power unit at the Finnish tractor manufacturer Valtra Plc. The experiment was performed at the Tampere University of Technology. The task was to assemble parts in correct order in the correct position and as soon as possible. Subjects performed two assembly tasks, one with paper instructions and another with AR instructions that were projected on one lens of a head-mounted display. The completion time of both tasks were measured. Afterwards the users filled the questionnaire about user experience and opinions about augmented reality. The completion times were compared with each other and questionnaire results in both experiments were evaluated. Results are analyzed and discussed.

Keywords: Augmented reality, assembly work, assembly instruction, CAD/CAM, Design for Assembly

1 Introduction

Augmented reality (AR) is a field of computer research which deals with the combination of real world and computer generated data. At present, most AR research is concerned with the use of live video imagery which is digitally processed and "augmented" by the addition of computer generated graphics.

The characteristic features of AR systems are the combination of real and virtual objects in a real environment; interactivity in real time; and registration (alignment) of real and virtual objects with each other. The basic components in AR applications are a display, a camera and a computer with application software [1]. Different kinds of hardware can be used to implement this, e.g. camera phones, handheld computers, laptops, head-mounted displays (HMD) etc. Here we are dealing with so called marker-based augmented reality. There is also augmented reality research studying markerless solutions in an industrial context, see for example [2].

The augmentation process is as follows (www.hitl.washington.edu/artoolkit/): The live video image is turned into a binary (black or white) image based on a lighting threshold value. This image is then searched for square regions. AR-software finds all the squares in the binary image. For each square, the pattern inside the square is captured and matched against some pre-trained pattern templates. AR-software then uses the known square size and pattern orientation to calculate the position of the real video camera relative to the physical marker. AR software computes the transformation matrix that describes the position, rotation, and size of an object. The virtual object is thereafter located in relation to that marker. Thus the user experiences video see-through augmented reality, seeing the real world through the real time video with virtual models. The diagram in Figure 1 shows the image processing used in AR-software in more detail and in Figure 2 shows an example how a virtual object is overlaid on the marker.

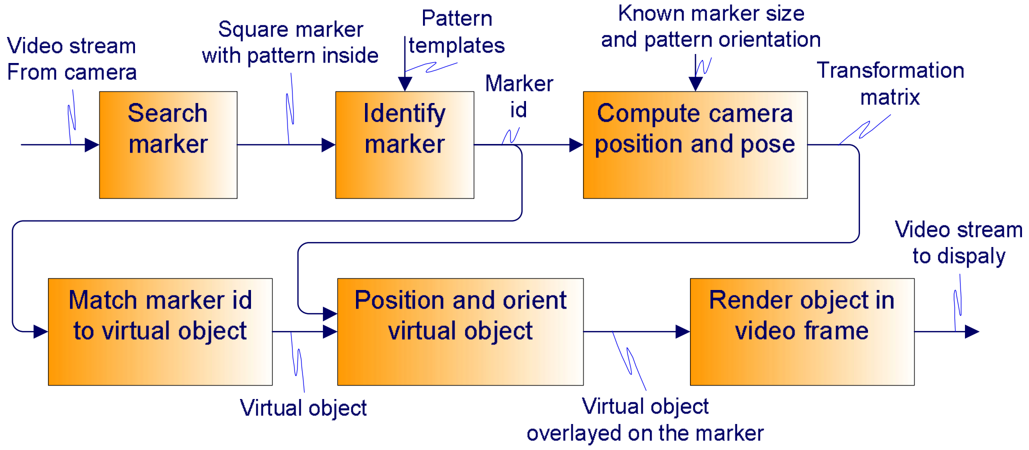

Figure 1. Image processing used in AR-software.

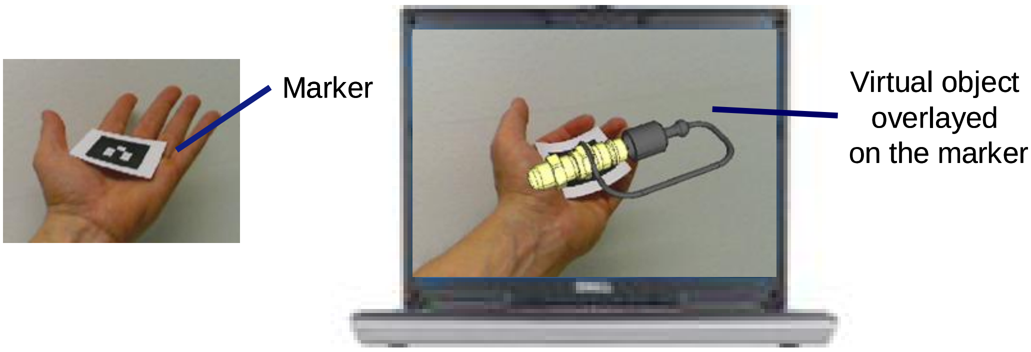

Figure 2. An example of the marker-based augmentation. From the video stream of the camera the marker is recognized and the corresponding virtual object is put on the palm.

Wearable AR systems have often been too heavy and big for industrial use. However, the rapid development of mobile devices has lead to small devices with enough processing capacity and long lasting batteries to enable light-weight mobile AR systems. Recently handheld computers [3], camera phones [4], [5] and miniature PCs [6] have been successfully used in AR applications. Indeed, we are today witnessing huge improvement in mobile computing units and graphics; also the recent HMD development is now led by gaming industry with the so called i-glasses, providing good full screen picture resolution with reasonable pricing. Examples of some more recent display devices are shown in Figure 3.

Figure 3. Examples of augmented reality display devices: hand held units and see through HMD.

According to [7] assembly is the capstone process in manufacturing. Assembly is the domain where many business strategies are carried out. On the high level, assembly has effects on market size and production volume, model mix and supply chain, and on the low level it offers partial answers to questions like factory layout, assembly sequences, automation vs. manual work, part joining etc.

AR methods are particularly well suited for complex, short manufacturing series or in a customized production factory environment. Each individual product may have a slightly different configuration: the order of assembling parts may vary for different products and/or the number of phases in the assembly line may be large. The traditional approach is to use assembly drawings (blueprints) and possibly instruction manuals with guiding pictures to describe the content of each work task. As the assemblies become even smaller, the need for guiding the worker with all available tools becomes increasingly important. The AR system may also reduce assembly times, accelerate learning of the assembly tasks and provide more quality assurance to the factory floor.

One of the first AR projects dealing with manufacturing was launched by Boeing in which Claudell and Mizell [8] described the challenges in aircraft manufacturing. Their concept was to provide a “see-thru” display to the factory worker, and use this device to augment the worker’s visual field of view with dynamically changing information. Recent studies of usability of augmented reality in assembly are few. Pathomaree & Charoenseang [9] studied how AR can enhance learning in assembly. The experimental results showed that their system helped persons to do assembly tasks better with the use of augmented reality. Also the system can reduce assembly completion times and the number of useless hand movements. Pathomaree and Charoenseang experimented with 2D and 3D puzzles, three pieces each.

Tang [10] described an experiment that tested the relative effectiveness of AR instructions in an assembly task. Three instructional media were compared with the AR system: a printed manual, computer assisted instruction using a monitor-based display, and a head-mounted display. An assembly task was based on Duplo blocks consisting of 56 procedural steps. For each step, subjects were required to acquire a part of a specific color and size from an unsorted part-bin and insert the part into the current subassembly in a specific position and orientation according to the instruction. Results indicated that completion times with these four media were: printed manual 14 min. 24 sec., computer assisted instruction using a monitor-based display 11 min. 25 sec., computer assisted instruction using a head-mounted display 11 min. 8 sec., and augmented instructions 10 min. 39 sec. Significant difference was in error rate. Users with AR system made an average ten times less errors during the task. Also measurement of mental effort indicated decreased mental effort in the AR case, suggesting some of the mental calculation of the assembly task is offloaded to the system.

2 Methods

Assembly experiment was carried out at the Tampere University of Technology in spring 2008. All the participants were students. Their task was to assemble parts of tractors accessory power unit in correct order and correct position using different kinds of assembly instructions. Students performed the experiment in a group of three persons. There were altogether 59 subjects attending the test with an additional observer in each test situation; all these subjects with the additional observers formed groups of three members in each test session. One member of each group used paper instructions, second member used augmented reality instructions and third member acted as an observer in both experiments. Assistant divided the roles randomly. Five groups of two members participated in this experiment. In those cases there was no separate observer.

Layout of the assembly space is illustrated in Figure 4. Parts needed in the assembly were located in two different locations. Bigger parts were placed on a wooden box on the floor (Figure 5a) and smaller parts could be found from plastic storage lockers on the table (Figure 5b). All locations of parts were labelled. There was a sticker with a name and an arrow that indicated the right part in the bottom of a wooden box. Plastic storage lockers that hold small parts like nuts and bolts had also the name of the part at each locker. There were also some additional parts that were not needed in assembly. These additional extra parts made the assembly task more realistic because in the actual factory environment there are usually more parts than needed for assembling one product. For example with longer grub screws it was possible to assembly two more directional control valves and fits and the rest of protecting covers. The rest of the additional parts were standard nuts and bolts.

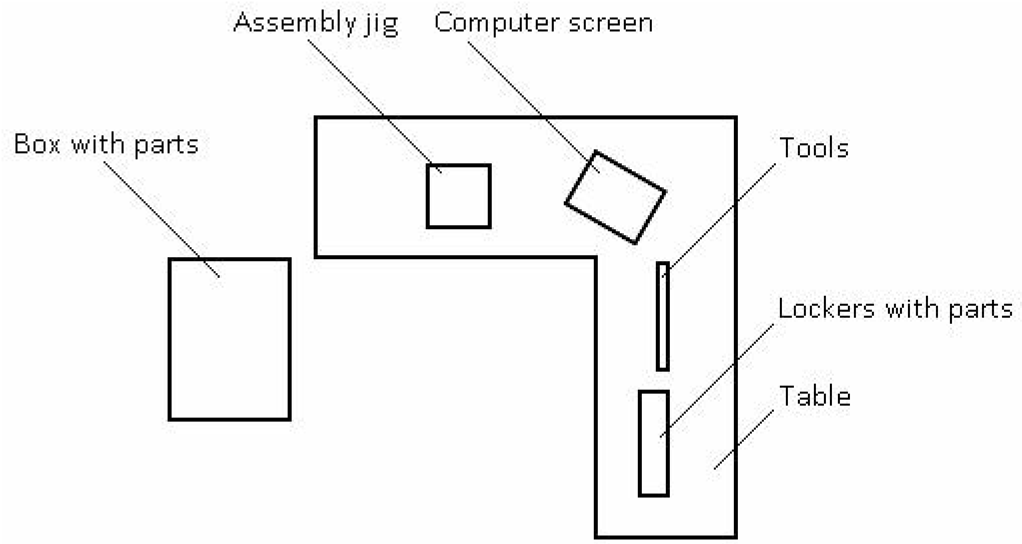

Figure 4. Layout of the assembly space.

a b

Figure 5. Parts in the box (a) and parts in plastic lockers (b).

The tractor's accessory power unit was assembled over a separate assembly jig. The first part of the assembly was mounted on the top of the jig with two butterfly nuts. The assembling subject was able to move the jig on the table to achieve the best working position (Figure 6).

Figure 6. The assembly jig with three markers.

There were some tools available for the assembly task. Tools consisted of Allen keys (5, 6 and 8 mm) and fork spanners (13, 17, 19, 27, 32 mm). Electrical tools like screw twisters were not used because of the participants' different skill levels of using special tools would have affected the results too much.

The assembly was first performed with paper instructions by one subject and thereafter, with computer instructions by another subject. During the first assembly the other subject, while waiting for his/her turn, read an article about AR instructions outside the assembly environment so he/she couldn’t see assembly phases or hear possible instructions that assistant said. The article was about assembling a cube with AR technology [11].

The paper instructions were introduced briefly to the subject before starting assembly task. The assistant performed timing of the assembly tasks. Paper instructions consisted of two mechanical drawings, assembly bill of materials (BOM) and assembly instruction. The first drawing represented a finished product from two different projections. The second mechanical drawing illustrated a one subassembly of tractors accessory power unit. All parts were numbered in proper assembly order in drawings to make assembly work easier. Parts were also in proper assembly order in BOM. BOM consisted of the names and the quantities of the parts. Assembly phases were straightened out more precisely in the assembly instruction.

Observer observed the assembly performance and wrote down notes with the help of a questionnaire. Observation was focused on possible errors that assembler made. These errors were divided on two categories. Observer calculated how many times assembler used wrong tool and how many times assembler tried to put parts to wrong position. Observer evaluated the overall performance also when the task was finished.

When assembly was done, the assembling subject filled his/her own questionnaire immediately. Next, the assembly was performed with AR instructions by another subject. Now the subject who had used paper instructions joined with the original observer to evaluate AR instructions.

A modified helmet was used for the purpose of showing AR instructions. Helmet had an integrated camera and a head-mounted display (HMD) (Figure 7). The camera was shooting markers attached on the assembly jig. The AR software recognized the positions of the markers and showed a 3D model of the next part in the assembly sequence in correct position in the display. Name of the part, assembly instruction and tool name were also showed in application. In addition to HMD, a 15” monitor was used because reading of assembly instruction from the HMD proved to be troublesome during the testing of the equipment. The monitor was placed on the right side of the assembly jig on the table. Many of the assemblers read the instructions and watched the animation from the monitor in addition to HMD. A screen shot of the view of the assembler can be seen in the next page (Figure 8).

Figure 7. The modified helmet with Micro Optical SV-6 HMD and Logitech web camera.

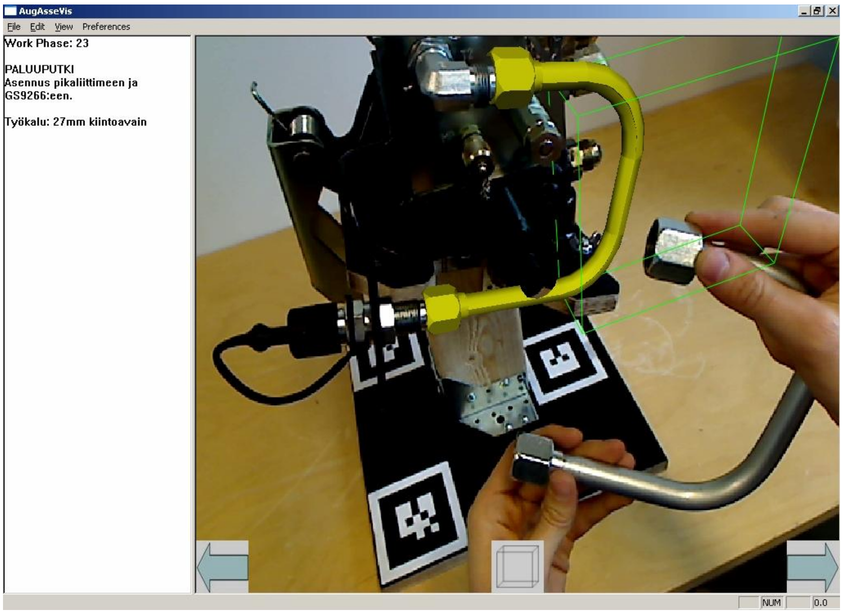

Figure 8. A screen capture from the AR application.

Before the task with HMD, subject was introduced the user interface of the AR application. The first part of the tractors accessory's power unit was displayed so the assembler could move the assembly jig and see how the application works. In this application the subject used computer mouse for moving from assembly phase to another. After short demonstration, assembly was started. As in assembly with paper instructions, one student observed working of the subject and when the task was finished, both the subject and the observer filled the questionnaire.

3 Results

The results are based on tests carried out by students at the Tampere University of Technology in spring 2008. There were altogether 59 subjects who performed the assembly: 49 male and 9 female subjects, 1 subject had not reported the gender. Roughly half of subjects had assembling experience; 32 subjects had only assembling experience (furniture assembling and the like), one had both assembling experience and AR experience and 2 subjects had only AR experience. Generally, the sample can be described as academic, technology oriented people.

Subjects were divided into tasks so that 30 subjects performed the assembling with paper instructions and 29 subjects performed it with AR instructions.

As the main result (Table 1), assembling was quicker with AR instructions than with paper instructions. On average, assembling with paper instructions took 36:34 (min:s) whereas with AR instructions it took 31:45. Also the usage of wrong tool and false positioning were on average less frequent with AR instructions than with paper ones.

Table 1. Statistics related to assembly duration and mistake comparison between groups using paper instructions and animated (augmented-reality) instructions.

	Instruction type	N	Mean	Std. Deviation	Std. Error Mean
Assembling duration (h:mm:ss)	paper instructions	30	0:36:34	0:07:42	0:01:24
	augmented-reality instructions	29	0:31:45	0:04:31	0:00:50
Observed frequency of using a wrong tool	paper instructions	26	1,96	1,455	,285
	augmented-reality instructions	25	,32	,627	,125
Observed frequency of false positioning	paper instructions	26	3,54	1,964	,385
	augmented-reality instructions	25	1,48	1,873	,375

The average difference on assembling durations between the groups using different instructions was 4 min 49 sec (Figure 10).

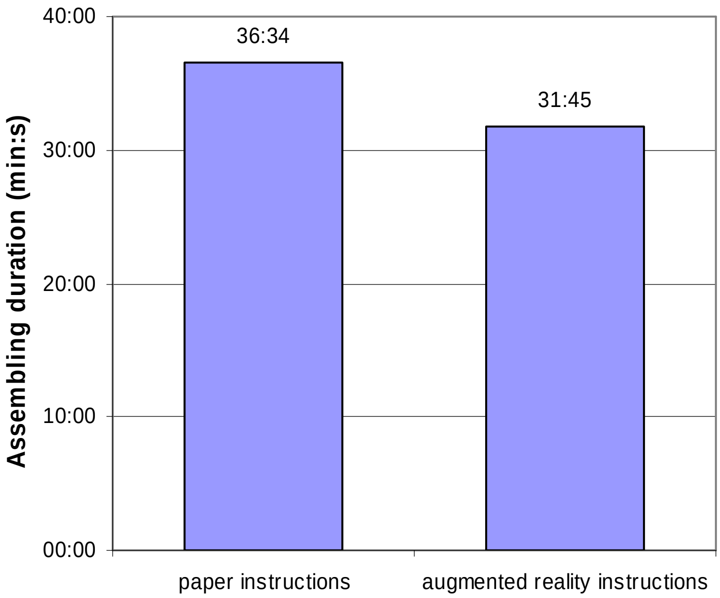

Figure 10. The average difference between the groups using different instructions.

Those having former assembling experience (33 subjects) were quicker (31:49) in the task than those who had not (25 subjects) (37:32) (Table 2).

Table 2. Statistics related to the performance duration between those who had previous assembling experience and those who did not have.

	Assembling experience	N	Mean	Std. Deviation	Std. Error Mean
Assembling duration (h:mm:ss)	yes (assembly experience)	33	0:31:49	0:05:55	0:01:01
	no (assembly experience)	25	0:37:32	0:06:32	0:01:18

As this experience was equally represented in both groups, difference in experience did not cause the difference between the performances in the different instruction groups (Table 3).

Table 3. Number of subjects having and not having assembly experience, related to instruction type used in the experiment.

		Assembling experience		
		no (assembly experience)	yes (assembly experience)	Total
Instruction type	paper instructions	14	16	30
	augmented-reality instructions	11	17	28
Total		25	33	58

Furthermore, those having used AR instructions had slightly more positive opinions about the easiness of the assembling task and they also rated instructions more positively, but also here, there was no statistical difference between the groups.

4 Discussion

The use of AR instructions resulted in faster assembling performance than the use of paper instructions. However, features that are useful or require further development were found with both instruction types. In the following, some of the most important observations are represented, relating mostly to the AR instructions.

The presentation of the form (3d model) and the animation of the way the part should be put to the right place, in the correct orientation, were found to be the most valuable features in AR instructions. The visualization of the assembly directions of the parts made assembling easier compared to the paper instructions particularly when the parts were assembled below the assembly. In this AR application, all the parts were animated separately. Some of the subjects thought that this feature clarified the assembly task but parts like screws needed in assembly of some specific part could have been all in the same animation. This would have made assembly work slightly faster because now some additional use of the computer mouse was required.

The subject saw the final product completely in paper instructions. Some subjects commented that the possibility to view the finished product between assembly phases would have been useful in the AR instructions also. Only virtual model of the part that was needed in each assembly phase was showed in the AR software. The software has an option to show also virtual models of previously assembled parts. In further research assembly with this option turned on could be tested.

Another definite target for development is the helmet with the display and the web camera. Operation with the helmet and wires was often experienced uncomfortable. Wireless and lighter solution would improve usability significantly. Also, the resolution of a low-cost head-mounted display is too low. We believe that this constraint will be solved in the near future. Fastening the camera on some stand and using regular computer display instead of HMD could be one of the alternative methods of implementation to research.

5 Conclusions

In this paper we have presented the usability study of augmented reality efficiency in assembly work. We observed the differences in assembling performance between the situations when paper instructions or augmented reality instructions were used. The assembly example was from Valtra Inc., Tractor company, and they are making these same kinds of hydraulic blocks for tractors from 10 to 20 every day.

There were altogether 59 assembly events; 30 persons did the assembly using paper instructions and 29 used augmented reality instructions. With paper instructions, the assembly task took about half an hour and with augmented-reality based instructions the performance was approximately five minutes faster. The usage of wrong tools during the assembly took place six times more often with paper instructions and trying to put a part in a wrong place happened twice as much with paper based instructions. This difference as well as all the other differences reported in this paper are statistically significant; statistical results were obtained with the t-test, performed with independent samples and the level of statistical significance was always at least $p<0.05$ unless otherwise mentioned.

6 Future work

Augmented Reality supported assembly work provides a powerful means for the rationalization of manufacturing systems. Important for the usability of AR are appropriate efficient data flow from design systems (PLM), sales support systems and enterprise resource planning systems (ERP). Our ultimate goal in future work is to combine product design and assembly. This would bring up benefits like consideration of assembly requirements already in product design phase, shifting the information created in design phase to assembly without translation (that is a possible error source), static assembly instructions can be changed dynamic (product changes are to be seen on assembly site real-time) and feedback from tools with sensors that guarantee right setups (e.g. wrench torques). The breakthrough of this project may alleviate the problem related with information transfer between product design and production, especially in the assembly phase when AR is used for assisting assembling.

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