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Augmented reality – A tool for improvement in the manufacturing industry

Bachelor's thesis in Mechatronics

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ABSTRACT

The globalisation of the manufacturing industry leads to higher demands on quality, time and flexibility in production. Augmented Reality (AR) has been in the field of research for the last 20 years and discussed whether it could be used or not in the manufacturing industry. Today's market on AR products is wide, where a various number of these products come with different advantages and disadvantages. This bachelor's thesis aims to analyse how AR can be used as a support tool for shop floor workers, and which of these products would be more beneficial for usage in the industry.

By analysing time and quality in several assembling tests, results were given that could be examined alongside with interviews to evaluate whether AR can be useful in the industry or not. Furthermore, the differences between the products of today's market were evaluated.

The study shows that improvements in quality can be achieved with the help of AR technology. The conclusion of this study is that the current products available on the market might need a little further development to be ready for implementation in an assembly line.

LIST OF ABBREVIATIONS

2D = Two-Dimensional

3D = Three-Dimensional

AR = Augmented Reality

OCR = Optical Character Recognition

OS = Operating System on a computer, for example Windows XP

QR = Quick Response, code that is built with black and white squares

SDK = Software Development Kit, extensions for programming software.

VR = Virtual Reality

Volvo XC90 (V526) = A car model from Volvo

INNEHÅLLSFÖRTECKNING

1. INTRODUCTION

1.1. BACKGROUND

This thesis aims to study the possibilities to improve information sharing in the manufacturing industry. The globalisation of the industry requires more flexible solutions, where information needs to be available at any site (Zuehlke, 2010). Whereas an industry shop-floor worker might need clear instructions of good quality and a maintenance worker need different instructions from time to time, Augmented Reality (AR) is an interesting alternative as a future information source. AR has been in the field of research for the past 20 years, where the most problematic part has been the hardware (Azuma et al. 2001). It is just until recently the technology has been capable of simultaneous tracking and rendering. As the hardware become more and more advanced, AR has been proven as a capable source of information in different areas of the manufacturing industry (Li et al. 2016) (Pettersson & Stengård, 2015).

Syberfeldt et al. (2016) has shown that AR has the potential to be a valued support for operators in the manufacturing industry. Although tests have been done to show the potential of AR technology, no evaluation has been found for the shop-floor worker in an actual manufacturing factory.

This thesis will, therefore, evaluate and set up tests in an industrial environment, where tests will be done with experienced and novice worker at IAC group's factory plant in Låssby.

1.2. PURPOSE

This thesis will be to investigate if AR can be useful in a manufacturing factory. The study will result in how AR can be tested and implemented in an industrial environment. Parameters such as quality and time will be considerable factors to see if AR is a technology to consider. Furthermore, different AR products will be evaluated and studied to get a greater knowledge on how far the technology has proceeded in its development stage.

1.3. DELIMITATIONS

The concept about the creation of useful instruction videos will just be mentioned. It requires a lot of knowledge about programming. The report will only demonstrate when and how the technology can be used through studies and show its advantages by applying the technology on a fixture that measures an interior component dimension. The reason why using a fixture instead of a station in the production is to avoid a moment of stress for the employees in the factory, which could have a bad impact on the results.

The experiment will test out a head-worn AR device with video display from XMReality because of the accessibility. The work is defined to investigate the improvement of assembly or the learning of this part in the production. Initially, perform simulated tests and if there is time, test on a suitable workstation in the production.

1.4. RESEARCH QUESTIONS

- *How can AR technology be useful in the production?*
  - It is of big interest how the implementation of AR technology has for kind of effect on the production. Through practical experiments, quality, time and how easily instructions are understood, will be evaluated and give an understanding how the factors are connected to each other and how they differ depending on the method.
- *Which technologies and approach are most suitable to use for the implementation of AR technology within production?*
  - There are several devices developed for “Augmented Reality”, divided into groups depending on display type. Head-worn is the group where the focus is, the other groups are hand-worn and spatial (Syberfeldt et al. 2016). A comparison and evaluation of these groups will determine the optimal technology for a specific work task.
- *What impact entails the change from current methods to AR technology?*
  - The economical aspect is always important for consideration. The results from the experiments regarding time consumption, learning curve and quality will give information how this technology can improve the business economics.

2. THEORY

2.1. AUGMENTED REALITY

Augmented reality is an enhanced reality picture that integrates virtual pictures into the physical world. Augmented reality can be described as a medium that enhances the reality with the help of different technologies. The usage of augmented reality can be found in different application areas, e.g. medical usage, military, construction tasks etc. (Sielhorst et al. 2004) (Livingston et al. 2002) (Fite-Georgel, 2011). There are some different ways that augmented reality as a medium are used today, e.g. a mobile device, where the camera records the surroundings and with the help of software development kit (SDK), a virtual object can be seen on the mobile display. This technology has been implemented for the use of either augmented reality glasses, which uses see-through lenses with displays in them or displays that work the same way as the technology for the mobile device.

The augmented reality system is built out of three main components. The three components are sensors, a processor and a display (Craig A B., 2013). The sensors could be a camera to record the physical world or a less complex type of sensor just to determine the state of the physical world. The processor is needed to evaluate the data from the sensors and to send the relevant information to the output screen. The display works as the connection between the virtual and the physical world, which makes the user sense it as if the two coexist.

To create an augmented reality these components, need to interact with each other. This application of augmented reality can be broken down into two simplified steps. First, it has to determine the current state of the physical and virtual world. Then it needs to display when the two worlds interact with each other.

2.1.1. SOFTWARE

The software will help the end user to do what he or she wants with the hardware. AR can be used in many different ways and the software decides the possibilities for the hardware. The main part of the AR glasses on the market today runs on Android platforms. Most of these glasses are supported by development by different SDKs.

For the development of AR, that scans fiducial markers or uses object identification.

2.1.2. REMOTE GUIDANCE

Remote guidance is a developed technique within the augmented reality technology. Several companies offer remote guidance and it can be very helpful in various situations. It differs from a phone call by not only have audio but also have a live broadcast on a display. For example, if an operator has trouble with a machine which requires help from experts. The operator can call the expert with an AR device and the expert can show the operator, with both virtual pictures and words, what he will have to do to get the machine start working again. When troubleshooting complex systems with help from experts it can be confusing with just audio guidance. These problems and misconceptions that can occur during phone calls can be reduced by using AR technology. This also creates the opportunity to document with video recording at the same time, which gives the company an assurance if an error should occur.

2.1.3. PREPROGRAMMED INSTRUCTIONS

Pre-programmed instructions is a new technique that can be used with augmented reality. It has just been introduced and got a great response. It is still a relatively unexplored area, but the development is making progress each day and several companies have shown products with great potential. With pre-programmed instructions, virtual three-dimensional images can be fitted over real objects and show different moments in for example an assembly. This creates opportunities for companies to increase their quality in the production and at the same time decrease the expenses. A clear example of what rather effect it could have for the production is the training for new employees. In the current situation, an experienced worker is needed to teach the new employee how the station works and the assembly of the product. Instead, these instructions could be available on a server that the AR goggles are connected to. The employee can browse through the instructions at their own pace and learning ability. Not only will the cost increase but it can also have a negative impact on the person. To have another person that watches and assesses every moment can create stress and nervousness, which can affect the personal health and the learning time.

2.1.4. SCANNING CODES

Cameras that can scan different codes are one of the most interesting possibilities that introducing of AR technology can lead to. The camera can scan a barcode, OCR-number, QR-code or such and display related information or instructions on an eligible screen. This information does not need to be in text form. It can be displayed as almost anything. For example, a virtual image of a module, arrows that point directions, availability of an article in or instructions of an assembly. The possibilities are many and can be chosen based on a suitable purpose. It can be a very helpful tool within logistics as well. Imagine an inventory along a wall with many different components. Instead of searching for the right one, you can scan a code and a marker will appear and show the location and the quantity of this component. This will lead to another advantage with AR. If the system feels that the quantity is too low, it can automatically ask the operator to place an order for more.

2.2. PUGH-MATRIX

A Pugh matrix is a decision matrix to rank different options against each other. In this case, there are multiple kinds of developers, all with their area of focus. A number of criteria options are set to compare the glasses in comfort, application area, price, usability etc. The matrix is weighted, which means that every criterion have a number between one and five, based on how important that criterion is to the practical experiment (Nancy, 2004). The alternatives are ranked based on the information collected from their websites, reviews and personal experience. One product is used as a reference and the other ones are given either minus, plus or a S. Minus means that the other product is less good than the reference, plus means it is better and a S means that the both products are equally good in that specific criterion. When every product has been compared with the reference in the matrix, the overall score can be calculated. All of the symbols are counted and are gathered in different rows, one for the plus signs and on for the minus signs. The overall score is the difference between the number of plus and minus signs. The score gives only an estimated winner due to the matrix is weighted. When calculating the weighted overall score, the sign has to be multiplied by its weighted value. Then the score is calculated in the same way as before, the difference between the values for the plus signs and minus signs.

3. METHOD

3.1. CHOICE OF WORK TASK

Five different work tasks will be presented. It is of importance that the task is moderately hard to use and understand. Nor shall the tasks be similar to each other. It is preferable that the tasks are found in different areas within the section. Either from measurement, quality control or maintenance. One of these tasks is selected based on a requirement of the specification. The specification includes the number of sub-operations and complexity.

3.2. SITUATION ANALYSIS

In this thesis, a study will be made on different learning methods on how to assemble an interior plastic detail for a Volvo vehicle on a calibration fixture. By interviewing expert operators, conclusions could be made on how instructions could be improved.

The study will represent some of the benefits and disadvantages when using augmented reality in production. Other areas where augmented reality can be implemented in some way will also be investigated.

A specified number of details produced has to go through a measurement test, to see if the interior detail has the exact dimensions, with an allowed offset. The details are assembled on a calibration fixture and measured with lasers. With these high levels of accuracy, it is of utmost importance that the detail is assembled correctly.

An experienced technician is interviewed to get information about fixtures in general. Questions that are asked are mostly about the instructions that are used currently, but also what errors that can occur and the consequences of those errors (Appendix A)

3.3. EXPERIMENT SETUP

In figure 1, the calibration fixture where the subject assemble the detail is shown.

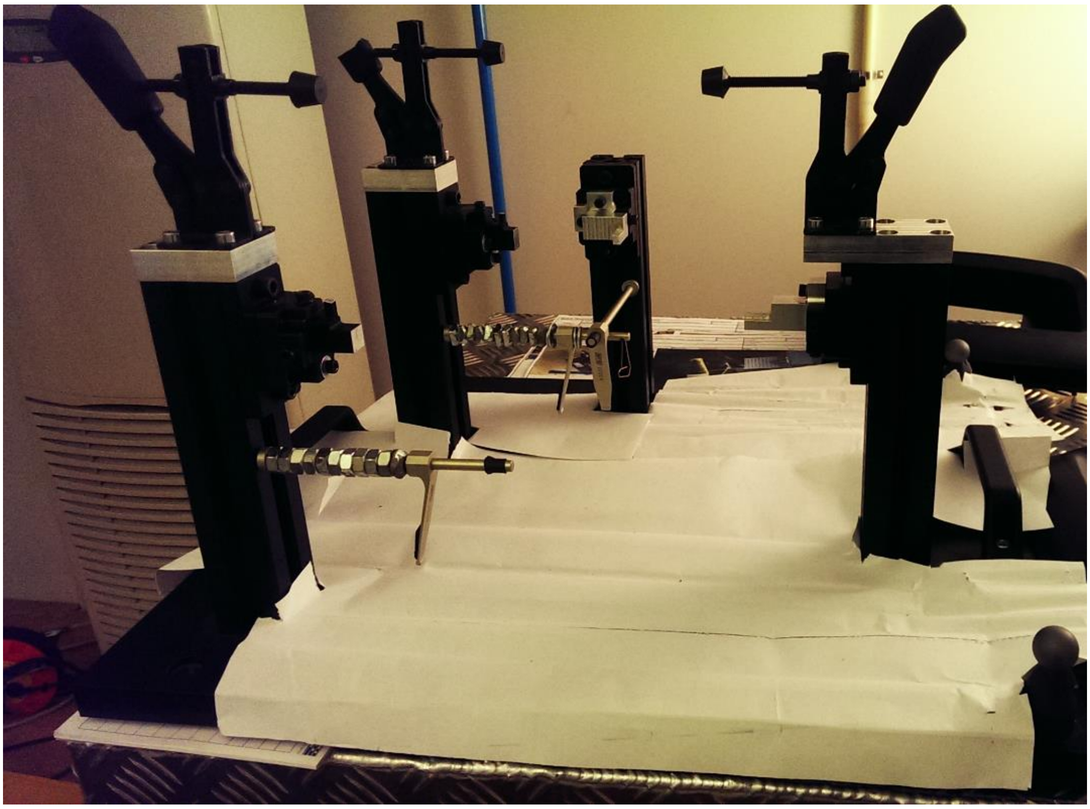

Figure 1 Calibration fixture - Workstation for assembling plastic detail

The test started with a quick introduction of the fixture and the AR glasses that were used in this test. The glasses were introduced on how they can be used as a tool. The glasses should be used as a support aid for the user, thus as a tool to facilitate instructions.

Every participant is going to start the test by answer a survey where basic questions will be answered e.g. age and gender. This survey will be used as a support for the test, to see how the participants differ from each other.

The test consisted of fifteen test persons. Where five persons assembled the detail with existing instructions and the remaining ten test persons was instructed through the AR glasses with the help of remote guidance. Every person did the test four times. Time, quality and how often the test person looks at the instructions or removed the glasses are the parameters that were controlled and measured. The parameters were compiled and compared in different data sheets.

Two test managers, where the first manager controlled the timer and counted every time the subject checked the instructions or removed the glasses, observed the test.

The second manager was controlling the number of faults made by the subjects during both of the tests. The second manager also acted as an expert during the remote guidance test (test group B).

The first manager was placed behind the subject and the workstation. Hence, this was the most suitable angle to observe the subject. To reduce possible stress from the subject, the decision was made not to record the subject and hide the timer from the subject's field of view. To record the test was also considered unnecessarily though the subject could easily be observed from behind the workstation.

The second manager controlled the faults that were made by the subject. This was done from the expert station during the remote guidance test. During the test with the existing instructions, manager 2 was standing right in front of the subject controlling the faults made.

When the test was done both of the managers controlled that the detail was assembled correctly. Any faults were discussed briefly and noted. Figure 2 shows a correct assembled interior component.

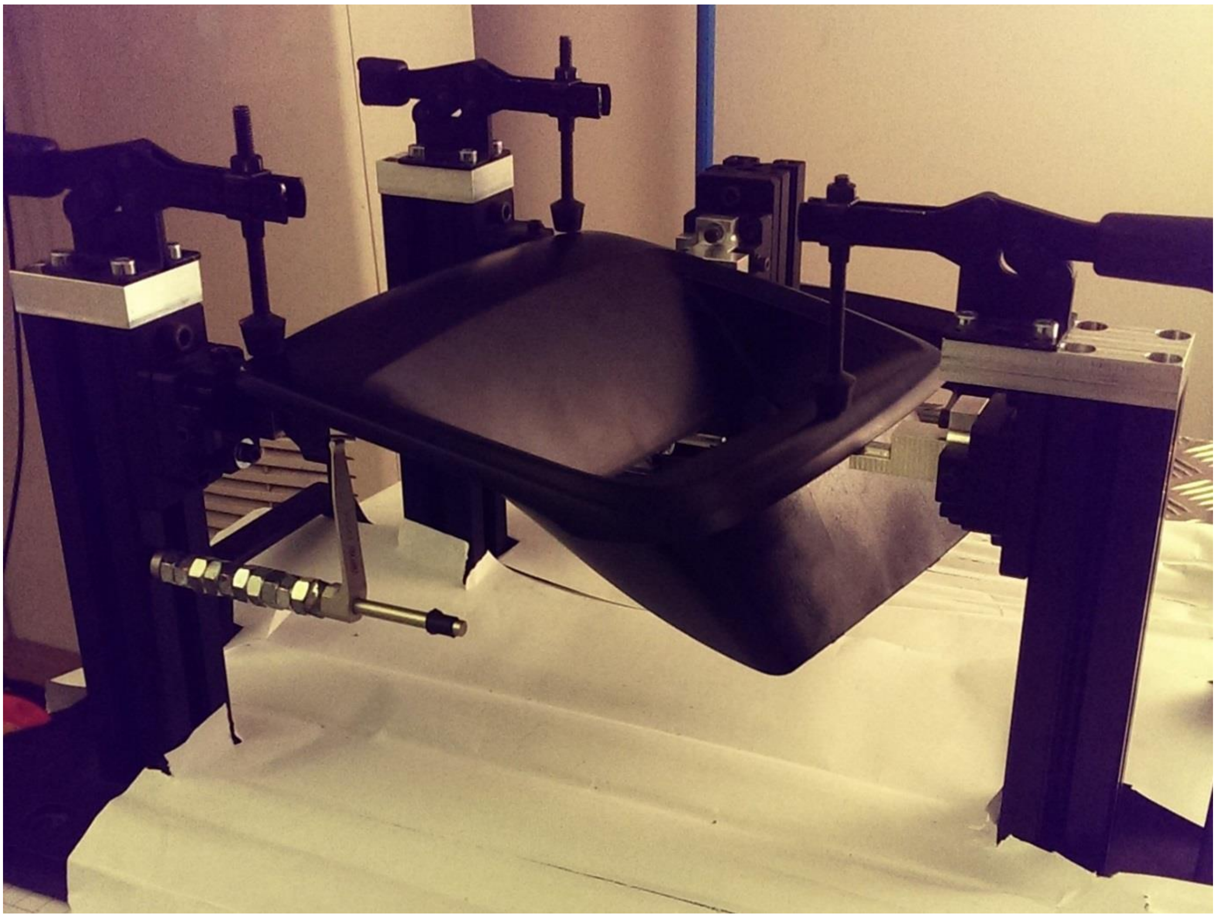

Figure 2. Correct assembled detail in fixture

3.3.1. OBSERVATION

Observation was chosen as the best method to collect the data for the parameters that were concluded in this test. Besides observing faults, checks and time, the observing manager can check for nonverbal feelings. Signs of stress, anger or joy, for example, can later be reminded when interviewing the subject, to achieve a stronger validity for the research. (Barbara B. Kawulich, 2005)

3.3.2. PRACTICAL

The test consisted of assembling a plastic detail on a calibration fixture for measurement controls. In a later stage, the detail is to be assembled on a dashboard for a Volvo XC90 (V526). The measurements performed is to control the dimensions of the detail.

The subjects were introduced to the calibration fixture and on how the test was going to be performed. They were also told to focus on the quality and try not to be stressed.

3.3.3. INTERVIEWS

The experiment begins with a short survey (Appendix B) that the test person will answer before the practical test. To maintain some information about the participants and their previous experiences with assembly tasks. In all experiments, it is of some importance to know about gender, age, employment and work experience. This will be compared with the results from the parameters: time, quality and checks, to see if any of the parameters can be interrelated with answers from the survey.

After the experiment has been done four times, an interview is held. There are two different types of questionnaire, which depends on if the test was with AR (Appendix C) or with the current instructions (Appendix D). These questions give the test person the opportunity to give feedback about the technology, if they felt any direct advantages and disadvantages with AR, how the instructions were, clear enough to understand them easily and some other general questions about the technology. The questionnaire about current instructions differed slightly. It contained questions about the current instruction, how they could have been improved and if the test person would prefer assistance instead of instructions in a text- and image form.

3.4. COMPARISON

A theoretical research about the comparison between the different developers of "Augmented Reality" technology are an important part of this work. Because of the high number of products on the market, the limit is set to six developers. This will give a more profound research about the chosen developers. They are chosen based on their technology and how their products differ from others. Many developers have similar solutions and then the product that has least information are screened out. The six products are ranked in a Pugh matrix to compare their specifications against each other. The glasses from XMReality will be used as the reference. They are also the glasses used in the practical experiments at IAC.

The different areas of use are also important to compare between the products. The comparison about application areas will work in a similar way as the specifications. A table will show if the products are compatible and developed for remote guidance, pre-programmed instructions, etc. The various developers' plans for the future products and technologies are interesting facts that will also be evaluated. The results are then compiled into a table to give a clear picture over which area a specific product is most suitable for.

4. RESULT 1. TESTING AND EXPERIMENT

4.1. CHOICE OF WORK TASK

The workstations evaluated included a titration process, maintenance of a glue nozzle, two different calibration fixtures and instructions for a pull test.

4.1.1. DIFFERENT FIXTURES

Two different fixtures elected as potential work tasks for the practical tests.

A calibration fixture is used to measure dimensions of details. The measurement is done with laser measurement tools with a high level of accuracy. The details have to be assembled in a predetermined sequence, otherwise, the measurement test will fail and the test will have to start over. Figure 3 shows the large fixture.

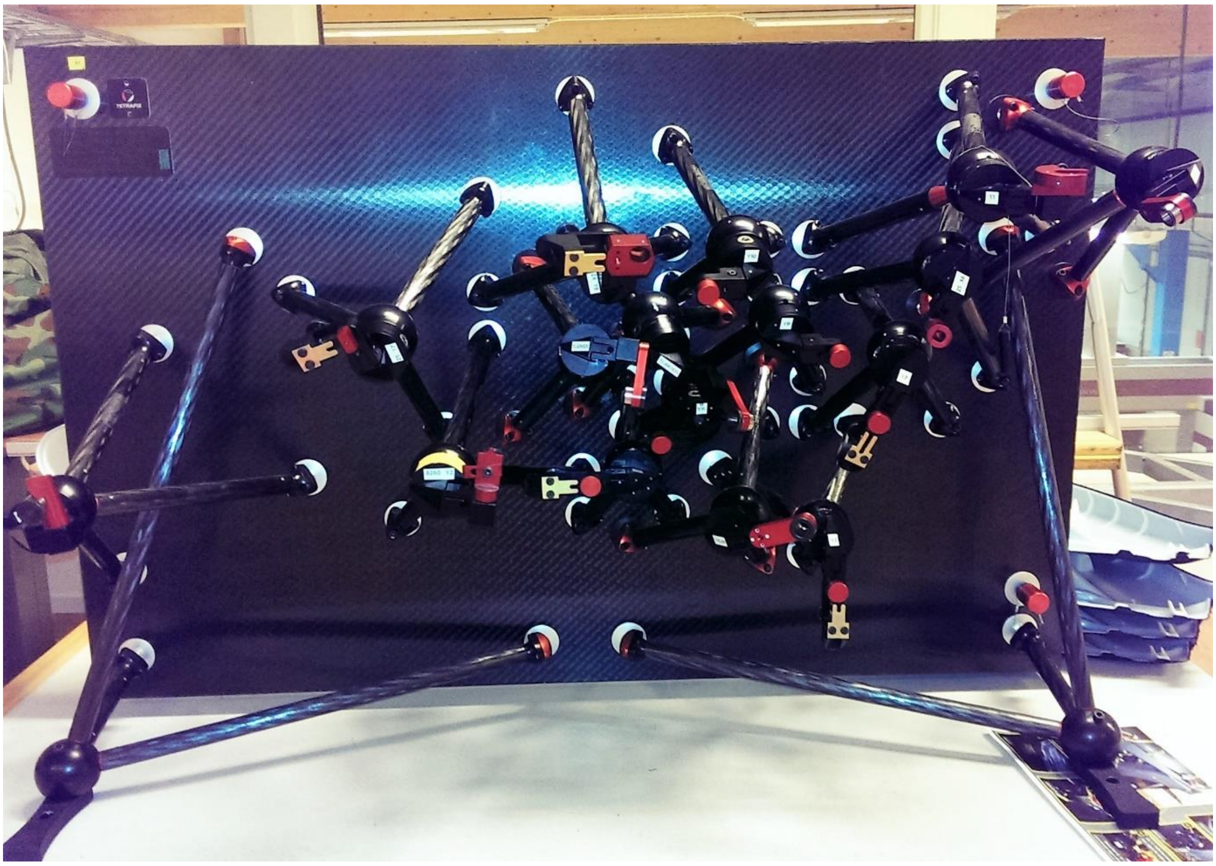

Figure 3. Large fixture. Shows the principle for a fixture.

4.1.2. TITRATION PROCESS

This is a procedure with chemicals to determine the percentage water in a solution after titration. A titration process can be explained as: *“A titration is a method of analysis that will allow you to determine the precise endpoint of a reaction and therefore the precise quantity of reactant in the titration flask. A burette is used to deliver the second reactant to the flask and an indicator or pH Meter is used to detect the endpoint of the reaction”* (ChemLab, Dartmouth College). Figure 4 shows the titration process.

Figure 4. Titration process with titrants.

4.1.3. GLUE NOZZLE

An industrial robot uses the glue nozzle, seen in figure 5, to press out an even layer of glue on an interior component. This is to fix the fabric, which puts on in the next station, with the component. These nozzles are repaired every second week and the problem is the quality of those repairs.

Figure 5. Glue-nozzle with O-rings that often replaces.

4.1.4. PULL TEST

The machine in figure 6 tests the required force to pull the fabrics from a plastic component. The results appear in a diagram with information about the force. This test consists mainly of computer moments, but also how to attach the test sample in the machine.

Figure 6. Pull test with operate panel on the right

4.2. DECISION MATRIX FOR WORK TASKS

A Pugh matrix, table 1, decided the work task with the best opportunities and that can reflect on a general assembly in the production. A scale (-1, 0, 1) evaluates the stations for each of the five criterions size, complexity, availability, sub operations and how connected they are to the production. If the station is ideal for test, it has value 1. Value -1 if it is far from good and 0 if it is neither. Explanation of the criterions shows in table 2.

Availability was a requirement before searching for a workstation. To have the station close to the section. This to get the best support possible. Thus, availability is the highest weighted criterion.

Connected to production considered as important as availability. The production is the target with the technology and the test should show the difference in time and quality for a related moment.

Size and the number of sub-operations are equally weighted. Testing on a bigger station makes it hard for the expert to guide the operator, since the narrow field of view. However, there is almost none restriction about how small the object can be. A high number of sub-operations makes the tests too long to complete and creates more things that can go wrong.

The work tasks in the production are formed to have low complexity and easy to learn. The structure of the experiment is comparable to a work task in the production. Therefore, complexity is only weighted one.

Table 1. Pugh matrix with the criterions and the different work tasks.

Work tasks		**Small fixture**	**Large fixture**	**Titration process**	**Glue-nozzle**	**Pull test**
Criteria	**Weight**	**1**	**2**	**3**	**4**	**5**
Size	2	1	0	0	1	-1
Complexity	1	1	1	-1	1	0
Availability	3	1	-1	1	0	1
Suboperations	2	1	1	1	1	1
Connected to production	3	1	1	0	1	0
Weighted Scores		**11,0**	3,0	4,0	8,0	3,0

Table 2. Definition of the criterions used in the Pugh matrix.

Criteria	*Definition*
Size	Outer dimensions of the workstation
Complexity	The complexity of the assemble
Availability	If the station is in the right section of the company
Sub operations	The number of sub operations in the assembly
Connected to production	How similar the station is to a moment in the production

Figure 7 shows the compiled result from the Pugh matrix.

The large fixture, the titration process and the pull test all had some minor or major weaknesses that would make the test unnecessary hard to implement. The large fixture was the first choice but unfortunately, IAC had to send it away. The titration process was very repetitive and did not have a connection to the production. The computer is the main tool in the pull test. When recording with the glasses on a computer screen it creates flicker on the displays. This was an annoying consequence and could cause headaches. The size was also a problem. The operator would be forced to move around too much.

The small fixture and the glue nozzle were the two competitors. Both were good options. They had the similar number of sub-operations. They were a perfect size to get a good overview for both the operator and the expert. The small fixture was the best alternative because another section maintains the glue nozzles.

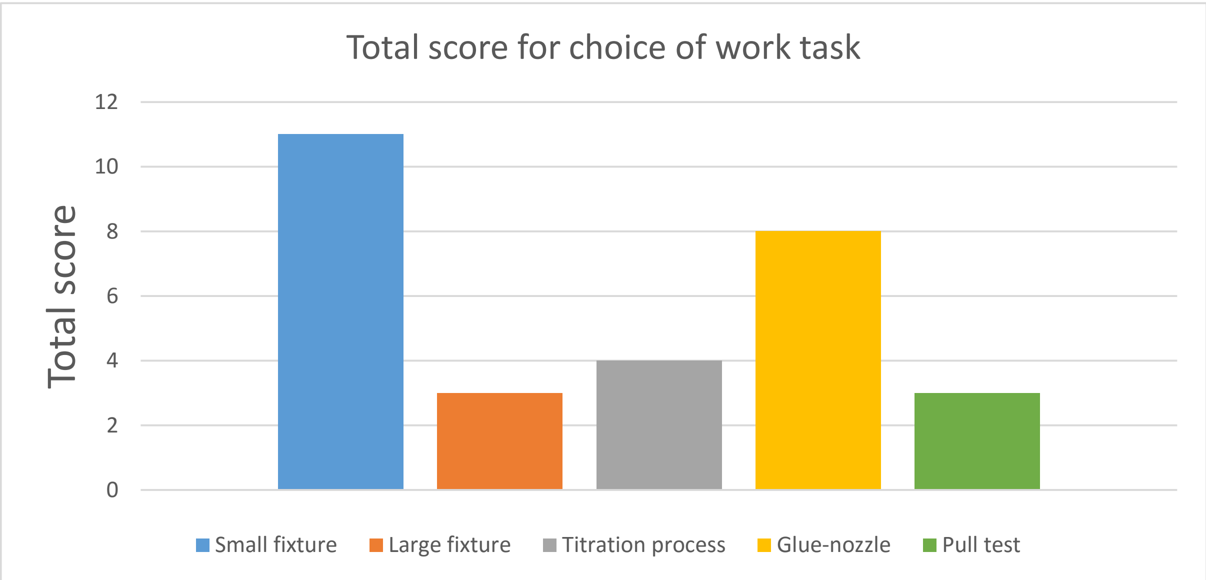

Figure 7. Compiled result from the Pugh matrix

Figure 8 shows a picture of the chosen work task. The fixture is used to attach an interior part to a Volvo XC90. The colour is actually black, but to get higher contrasts it has been dressed in white paper. It has four different horizontal contact surfaces and three vertical. It is very important that the detail has contact with all of these surfaces or else the detail will not pass the measurement test in the next stage. Underneath the placed detail, three identical straining arms will hold the detail in its place. It is important to maintain a small amount of pressure on the component to prevent it from moving when placing the straining arms. Lastly, the three locks on the top fold down also to prevent the detail from moving with help from the friction between the detail and the rubber on the lock arm.

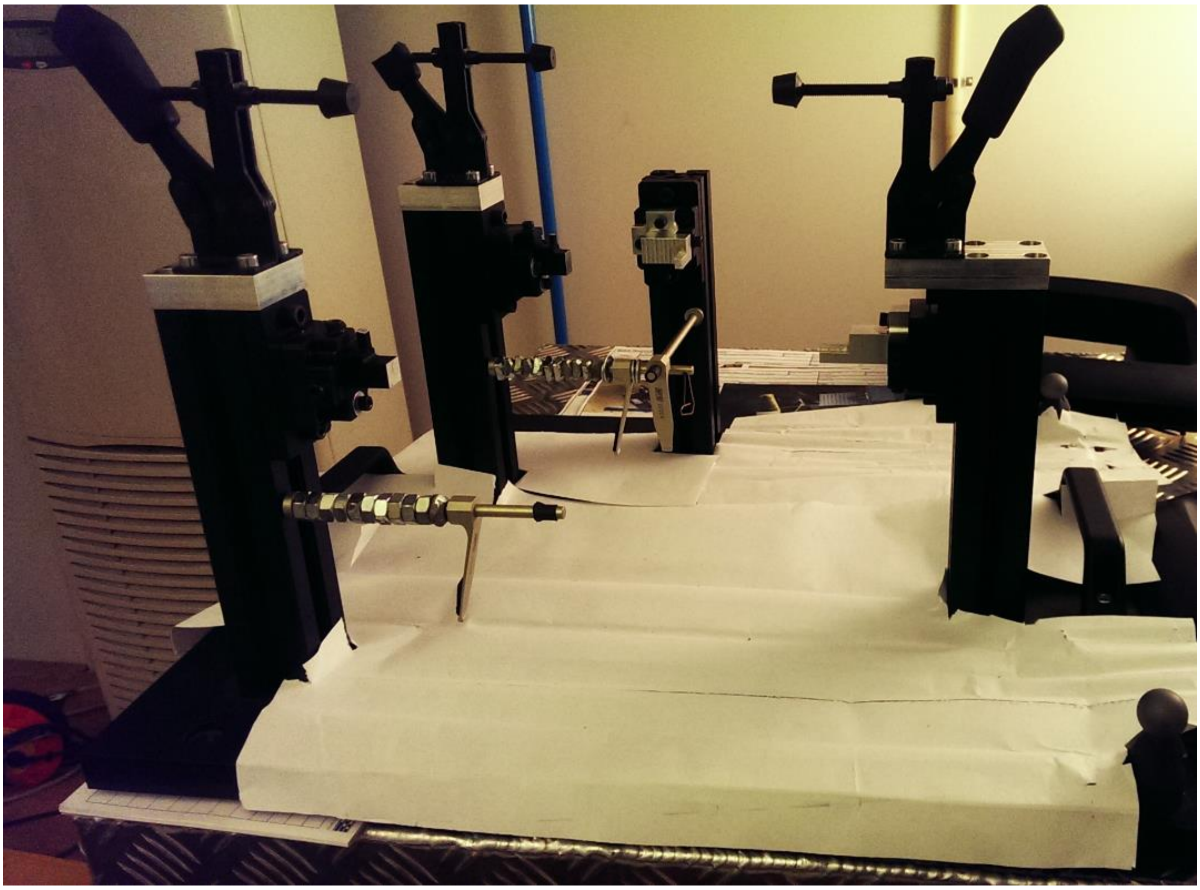

Figure 8. The chosen fixture.

4.3. SITUATION ANALYSIS

The following text is based on the answers from an interview with an experienced employee. Instructions for all of the fixtures are placed on the local intranet. When learning a new fixture, the technician needs to log onto a computer and find the right instructions. This may seem tedious. Sometimes the instructions cannot be reachable due to different operating systems (OS) on the computers, which is a problem. The right instructions are printed and should be near at hand throughout the assembly. A new fixture takes approximately five times to learn but after that, the instructions are more rarely used. To ease the training of a fixture and encourage employees to follow the instructions consistently, the right instructions should open directly at a new measuring.

The instructions are verified after they have been written to ensure the clarity and the simplicity. They should be sufficiently easy that a person with no experience can assemble it without any major difficulties.

Several errors can occur during an assembly. Instructions with images do not tell how much pressure to put on the interior component. The right amount of pressure can be crucial on some interior components. If the component is placed incorrectly, then the measurement will complain about wrong dimensions of the detail and the employee will have to reattach the component in the fixture. The same thing can happen if the tensioning devices are strapped in the wrong order. The measurements can be very sensitive of such things and can only be noticed and rectified after getting the results back.

4.4. TEST RESULTS

This chapter will present the results in three different ways. The first part will present all the results of the test combined. Primarily, two trial tests will be shown, with the results from it and why it was concluded from the test in whole. Other results that will be presented are results from the subjects from both group A and group B without any previous experience of fixtures. Results from the test exclusively with AR instructions will also be presented.

4.4.1. COMBINED RESULTS

The combined results are from both group A and group B. Results from both of the parameters time and quality will be presented here. The first two tests made will be shown

4.4.1.1. PRELIMINARY TEST RESULTS

The first two tests done was with existing instructions on two subjects with no experience of fixtures. These two subjects received pointers in what they did wrong in the first test, which resulted in that the following tests showed inaccurate results especially in time, but also in quality. Differences in the time between the first two subject and the latter two can be seen in table 3.

Table 3. Preliminary test results, test 2,3,4, shows inaccurate times (EI=Existing instruction)

Result EI:	Time: min,sec				*Experience of fixtures?*
Test:	1	2	3	4	
1	19:10	00:41	00:31	00:21	No
2	11:01	00:46	00:50	00:53	No
Average time:	906 sec	43 sec	41 sec	37 sec	

4.4.2. COMBINED RESULTS OF TIME

Figure 9 shows test result combined, where two graphs show the difference between subjects using existing instructions and subjects instructed by remote guidance with AR.

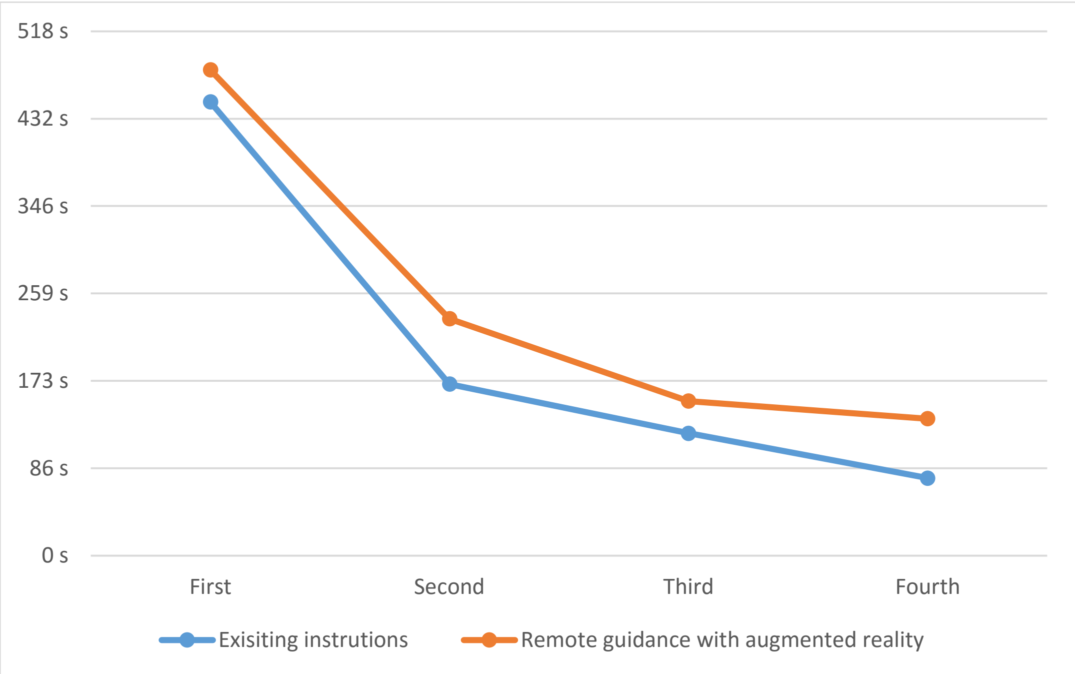

Figure 9 Graph showing assembly differences between existing instructions and remote guidance with AR

The first test group consisted of three persons, where one of the subjects had been working with similar fixtures before. Two persons were men and one was a woman. The ages differed from 34 to 47. The first group, called test group A, assembled the detail out of existing text and picture based instructions. What was noteworthy, was when a subject had done similar working tasks before, the test could be done with a lot less effort and faults than otherwise. The inexperienced subjects had problems understanding the instructions. Which resulted in that most of the time consumed was given to understand the instructions and to get the detail in its starting position. This can be seen in table 4. When the subjects understood how to position the detail correctly, the time consumed during the test lowered drastically. Even though the time consumed lowered, faults when assembling the detail still occurred.

Table 4 Shows assembly times with existing instructions

Result EI (Group A)	Time: min,sec				*Experience of fixtures?*
Test:	1	2	3	4	
3	11:46	04:40	03:15	02:00	No
4	02:45	00:30	00:25	00:25	Yes
5	07:55	03:19	02:23	01:25	No
Average time:	449 sec	170 sec	121 sec	77 sec	

The second group, called test group B, consisted of seven persons, where four out of the subjects had been working with similar fixtures before. Six persons were men and one was a woman. The ages differed from 29 to 46. Test Group B assembled the detail with the help of remote guidance with augmented reality. Two subjects deviated from the others. Where one of these subjects were almost two times faster than the average time of the other subject with experience of fixtures. As can be seen in table 5, the results of the time point in the same direction for an experienced and a novice in test three and four.

Table 5 Shows assembly times for remote guidance with Augmented Reality

Result AR (Group B)	Time: min,sec				*Experience of fixtures?*
Test:	1	2	3	4	
6	04:53	02:08	01:48	01:43	Yes
7	06:06	03:06	01:48	01:48	No
8	02:48	01:31	00:56	00:59	Yes
9	04:35	01:58	01:44	01:08	Yes
10	04:47	02:37	01:51	01:55	Yes
11	08:40	04:40	02:25	01:40	No
12	08:12	03:31	02:12	02:04	No
Average time:	8 min 0 sec	3 min 54 sec	2 min 33 sec	2 min 15 sec	

4.4.3. COMBINED RESULTS OF QUALITY

The quality results of the test are shown in table 6, where quality is measured in the number of faults made when assembling the plastic detail on the calibration fixture.

Table 6 Table of quality - Number of faults made in both group A and group B

Result Quality:	Number of faults				*Experience of fixtures?*
Test:	1	2	3	4	
EI (Group A):					
3	3	3	2	2	No
4	0	0	0	0	Yes
5	3	2	1	0	No
AR (Group B):					
6	0	0	0	0	Yes
7	0	0	0	0	No
8	0	0	0	0	Yes
9	0	0	0	0	Yes
10	0	0	0	0	Yes
11	0	0	0	0	No
12	0	0	0	0	No

The table displays the amount of faults made in both group A and group B. Where group B has no faults made regardless of previous experience of fixtures. However, the subjects without experience in group B encountered problems with how the fixture was operated and had to repeat parts of the sub-operations. The repetitions of the sub-operations resulted in a longer time of assembling, as can be seen in table 5.

4.4.4. RESULTS WITHOUT EXPERIENCE

In this subchapter, results will be presented for the subjects without any previous experience of calibration fixtures. The results of time and quality will be compared and presented on the correlation between the two parameters.

4.4.4.1. TIME RESULTS WITHOUT EXPERIENCE

Figure 10 displays time differences between group A and group B for subjects without experience. The results are based on two subjects from group A and three subjects from group B.

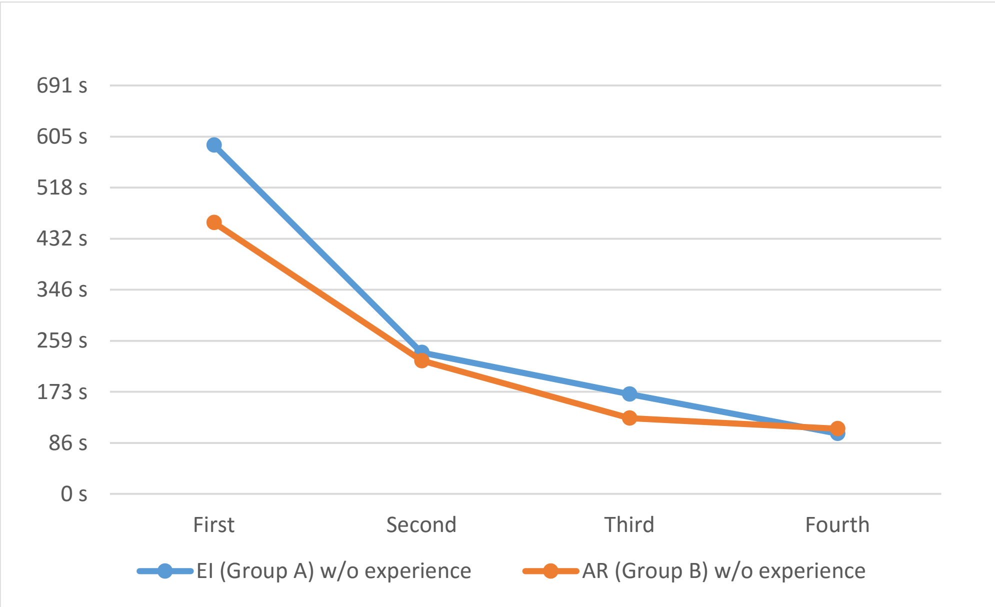

Figure 10 Average assembling time for group A and group B without experience

The figure shows that the first three tests are faster with remote guidance with AR. The fourth test is faster (by 9 sec average) performed by group A, who assembled the detail with the help of the text- and picture-based instructions.

4.4.4.2. QUALITY RESULTS WITHOUT EXPERIENCE

The results from the quality measurement are shown below in figure 11. This is the results from the subjects without experience in respective group A and group B.

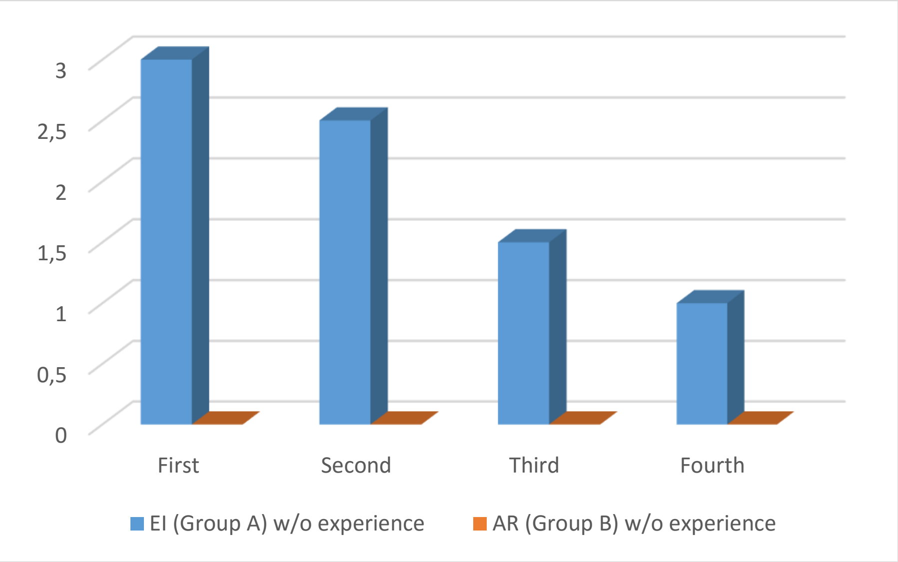

Figure 11 Quality results - Figure displays quality results for both groups

As can be seen in figure 11 the results from group A and group B differ a lot from each other. Group B, which is the group instructed by remote guidance with AR has zero throughout the whole test. However, group B had some difficulties assembling the detail correctly in the first two test but corrected the fault as the test proceeded. Group A, on the other hand, has an average fault over one fault per test throughout the whole test.

4.4.4.3. CORRELATION TIME AND QUALITY

Group B are slightly faster in the three first tests and has zero faults made throughout the whole test. Group A, subjects assembling with existing instructions, are both slower and has more faults made in the first three tests. In the fourth and last test, group A is faster but still made some faults assembling the detail.

Group B shows, therefore, better results in both quality and time when learning a new assembling task.

4.4.5. TEST WITH AUGMENTED REALITY

During the test with instructions from remote guidance with AR, the result showed differences in time assembling the plastic detail on the calibration fixture. The greatest difference is in the first test. Following in the second, third and fourth test a flattening can be seen between the two average times in figure 12. The differences in the third and fourth depend mostly on the feeling the subject has for the fixture, which is something that comes with time and repetition. Differences in the first test are because of that the experienced subject is used to work with calibration fixtures and knows how the different sub-operations are performed.

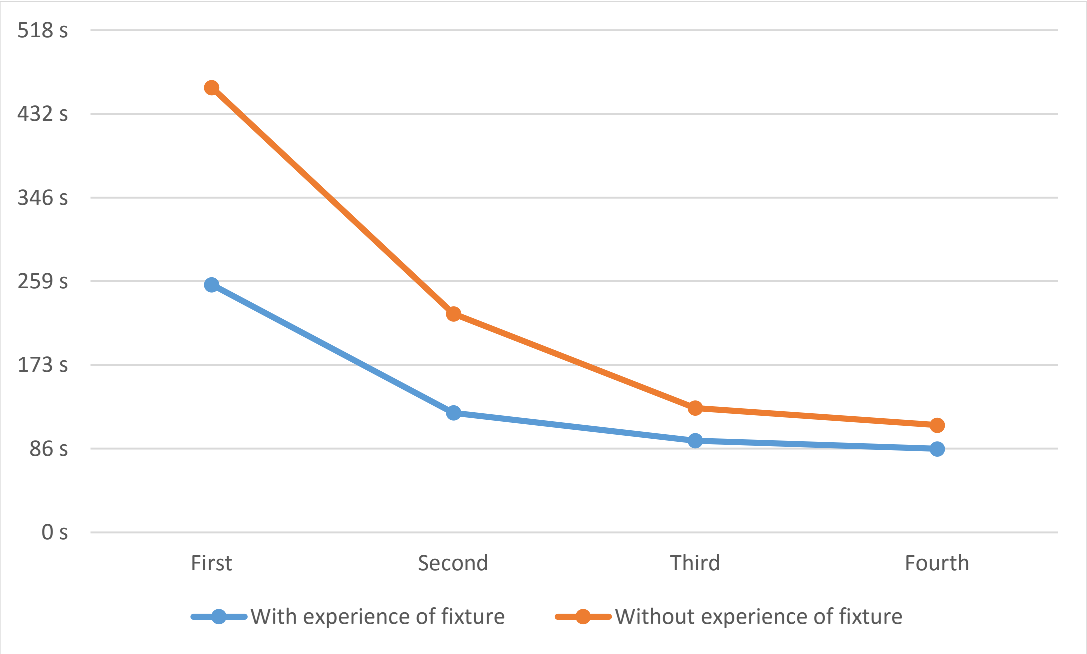

Figure 12 Time differences between assembling with and without experience through remote guidance with AR

4.5. OPERATOR OPINIONS

This chapter contains a summary of the answers from every test subject using existing instructions and with AR glasses.

4.5.1. WITH AR GLASSES

All the test subjects had previous experience from assemblies of some sort. Half of them also had experience from other fixtures and a few even had experience from the used fixture. The test subjects agreed that the instructions helped them. Especially with small details like the placement of the component and the order of the brackets. The experienced persons worked from memory but the instructions were necessary when it came to the order. After one assembly, they had no trouble to assemble it again without instructions. It showed how effective the technology was for refreshing the memory.

AR technology was obviously a very exciting method for the test subjects, but all pointed out weaknesses with the current hardware. Updating the hardware would be almost obligatory for them before consider using it. The majority had trouble with the sense of depth, low contrasts and the limited field of view. They needed either to lift up the glasses or look under the lenses to be able to assemble the component. Some suggested glasses with optical see-through. Be forced to alternate between looking at the displays and beside the lenses created another problem, adjust the eyes. This is tough for the human brain and two of the subject felt a little dizzy afterwards.

The instructions clearly helped for the test person. No one did an incorrect assembly. It happened that the detail was wrong in placement, but the expert could point this out right away. The instant feedback was one of the most common advantages the test subjects saw with the technology. Some mention the advantage what an expert does not need to be in the same place, not even the same country. They specifically mentioned the conveyor system ETON. A company in Germany makes it and they need to, in some cases, send an expert if a failure occurs.

Everyone saw the potential the technology has and understood why many companies invest in AR technology. They were positive to use AR for future work after upgrades of the hardware and made the glasses more ergonomic and slim.

4.5.2. WITH EXISTING INSTRUCTIONS

Just one person had experience from fixtures before. This test person did not have trouble to complete the task without faults. The person, however, did point out flaws with the instructions. An experienced employee has a better sense about the placement in a fixture. Different fixtures do not look the same but are similar in other ways. That gave the subject a great advantage. According to the test subject, the instructions were not clear enough for an inexperienced person and should be clearer and have images that are described better. The statement of clearer and more describing images did all test subjects shared. Some were even close to giving up. Moment of stress and frustration were other reasons why the assembly went wrong. One manager had to oversee the assembly all the time and made the test subject stressful to complete the task. The detail or the fixture do not have any distinctive marks or track that tells if the detail is in the correct place. Some subjects assembled the detail correct but later changed it because it did not feel like the correct position. The majority of the test subjects thought that the instructions just were confusing and it would probably be easier to assemble it with logical thinking. The only necessary part with the instructions was the sequence for the brackets.

Lastly, all the subjects would prefer visual help in some way. Either with AR technology or with someone standing beside for instant feedback. At least for the first time assembling.

5. RESULT - COMPARISON

5.1. COMPARISON

In this chapter the results from the comparison of six different glasses. Four of them are on the market and the other two are released in quarter three this year. The result shows the glasses with most potential.

5.1.1. PUGH MATRIX

In table 7 shows the chosen decision matrix to compare the different products. The glasses from XMReality is a reference to the other products and the matrix shows if the compared products are worse, equal or better in nine vital criterions that characterizes a great AR device. The weighting number, in this case, called “Importance Rating”, describes how important the criteria is. Availability and application areas are the highest rated because the project is about how the situation on the market is right now and it is important that the glasses is not limited to a specific work task. Be able to use the same pair of glasses for several different work tasks and station should be one of the main reasons to invest in the technology. Limitation of areas of use creates unnecessary problems.

It is preferable with plug-and-play glasses with no more than a few steps before they are up and running. Hence, usability has a high rating. Battery life and comfort is equally important. More difficult work tasks can take hours to complete. Therefore, it is important with a battery with high capacity and a device that is firm and without distinguishing pressure points.

Weight is less important as comfort because if the device has a well-constructed design then the weight is spread out more around the head. Portability is one of the main functions of AR technology. Almost every developer on the market have a similar thought; AR devices are a popular trend because of the ease to transport and carry around. Same for the criteria development opportunities. Because they have a similar vision for future devices, these criterions are slightly less important.

The abilities weight heavier than the price. The consumers want a product that satisfies the requirements. This is more central than if the product is cheap. Cheaper products can mean in many cases an underdeveloped product.

Table 7. Pugh matrix with compared products

Key Criteria	Importance Rating	XMReality	EPSON bt-200	Meta 2	Vuxiz M100	Atheer AiR	Penny C wear
			Solution Alternatives				
Weight	3		+	S	+	+	+
Comfort	4		S	S	-	+	S
Availability	5		S	-	-	-	S
Development opportunities	3		+	+	+	+	+
Application areas	5		+	+	S	+	S
Price	2		+	+	+	+	+
Usability	4		-	-	-	-	-
Portability	3		S	-	S	S	S
Battery Life	4		-	+	-	-	S
Sum of Positives			4	4	3	5	3
Sum of Negatives			2	3	4	3	1
Sum of Sames			3	2	2	1	5
Weighted Sum of Positives			13	14	8	17	8
Weighted Sum of Negatives			8	12	17	13	4
TOTALS			**5**	**2**	**-9**	**4**	**4**

Concept Selection Legend: Better +, Same S, Worse -

Figure 13 shows the compiled total score for every product in a bar graph to clarify the result from table 7. The y-axis describes the value of the total score.

EPSON moverio bt-200 is the product with the best overall score according to the matrix. It is just in battery life and usability fails over the reference. The AiR glasses from Atheer and Penny C wear are close behind. The three products have numerous similarities in both design and software. Worth of notice is that these companies have spent much on advertising about their product and tried hard to reach out to potential buyers.

Meta 2 is soon on the market for everyone to buy. They have concentrated their resources to create a multifunctional tool with a simple platform as a base. Meaning that the programmers can develop their own applications with an easy access. This is truly a remarkable product in engineering perspective. Unfortunately, there is a major flaw with Meta 2. It only works when connected to a computer. To be able to move around with the glasses is vital in many cases and can be the reason why Meta 2 can have trouble to compete with other products on the market. At least in an industrial environment.

Everyday use and a competitor to Google Glass was the thought when Vuzix created the M100. The design is comparable to an ordinary pair of glasses with an external display on one of the lenses. They are easy to use, discrete and does not block of the eyesight in the same scale as other products. The simplicity over the M100 makes that they cannot compete with other glasses in industrial environments, but can be useful in management and office environments.

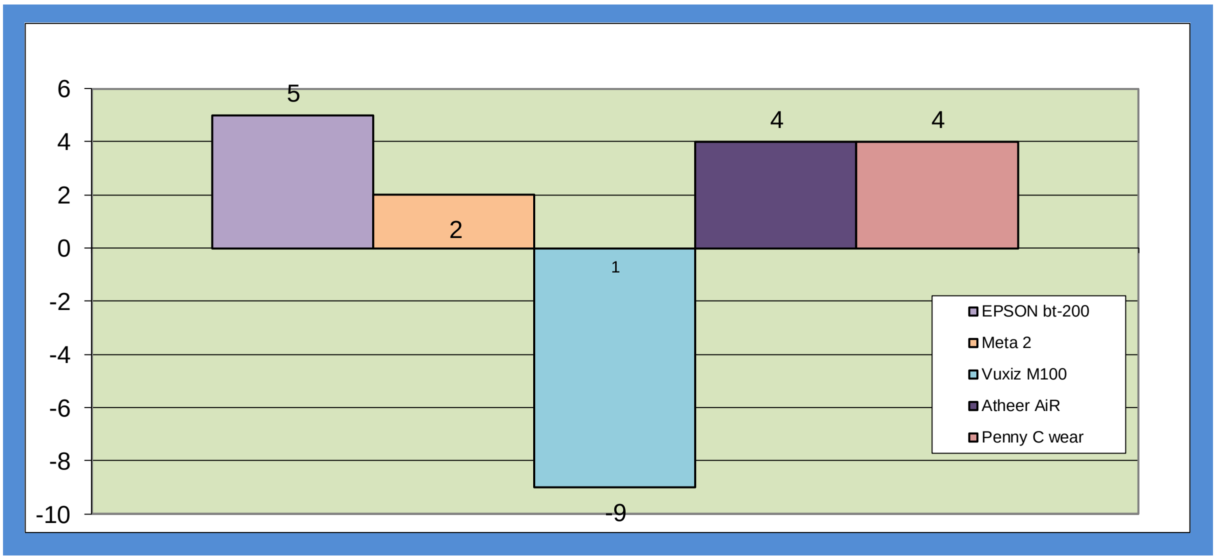

Figure 13. Compiled result from the Pugh matrix

5.1.2. SPECIFICATIONS

Table 8 shows information compiled from data sheets and articles. The hardware and the performance are important knowledge when choosing between products. The factors are set depending on the application area, in this case, important factors when using the glasses for assemblies.

Factor weight describes only the weight of the glasses. Other components that are necessary for example a tablet or mobile phone are not included. As you can see, the weight differs between the products. This is because some developers have an external device with most of the hardware, other have created a product with the hardware integrated into the glasses.
Unfortunately, information about price and weight could not be found for Penny C wear.

Transparent lenses mean that if the operator is available to look through the lenses. Optical has lenses with transparent glass or plastic where an image is projected on the lenses. Glasses with video see-through have integrated displays in the lenses. Most of the developers have optical see-through, except for XMReality and Vuzix.

It is very important to have a decent camera. On today’s market, a VGA camera is common but is disappearing more and more in favour to cameras with high definition and 3D-vision. Compare XMReality and EPSON bt-200 against the next generation of glasses, Meta 2 and Atheer AiR. The table tells that much focus lays on improving the hardware, such as resolution and the camera.

Field of view is also evolving at a quick pace. A larger field of view gives the operator more space to use for applications and user-friendly.

EPSON, Atheer AiR and Penny has developed similar products. All three has the ability to create own functions and applications using a program as Unity3D. It is originally a software used repeatedly in the market of game development. With experience and knowledge in programming, creating own applications becomes easy for these products. It also applies to Meta 2.

Table 8. Comparison of specifications

Factor	Product	XMReality	Epson bt-200	Meta 2
Price		$7,900	$700	$949
Weight		400 grams	88 grams	420 grams
Transparent lenses		Video see-through	Optical see-through	Optical see-through
Resolution		800x600	960x540	2560x1440
Camera		VGA	VGA	720p
Field of view		40° binocular	23° binocular	90° binocular (diagnonal)
OS		Windows or Android	Android	Windows
Battery life		2.5h	1.5h	Powered by computer

Factor	Product	Vuzix M100	Atheer AiR	Penny C wear
Price		$1,080	$3,950	$3,000
Weight		44 grams	135 grams	66 grams
Transparent lenses		Video see-through	Optical see-through	Optical see-through
Resolution		240x400	1024x768	873x500
Camera		1080p	2x4MP RGB and 3D Time-of-Flight	Intel real sense R200
Field of view		15° monocular	50° Binocular	42° Binocular
OS		Android or iOS	Android	Windows or android
Battery life		1h	---	3h

6. DISCUSSION AND ANALYSIS

6.1. PRACTICAL EXPERIMENTS

A few aspects made the selection of workstation a little bit harder than predicted. The glasses that was tested did not have see-through lenses. Instead, it had integrated displays and it created some problems. Feeling for distances almost completely vanished and the contrasts were reduced. The number of options was also limited by the size of the section. To get the help needed it was crucial that the work station was within the section. Although it would not be optimal to have the test on a black fixture, we choose it anyways. Mostly because it was most similar to a work task in the production than the other options.

We could have been more consistent with the execution of the experiments, both when testing current instructions and using AR. The tests had some few conditions that should be the same for all test persons. After a test, we could feel that it should have been done in another way to be more similar to the reality. This was a clear problem after the two first test with the existing instructions. Thus, these two tests were considered as invalid results and the test implementation was changed to get a more accurate result.

The results point in the same direction as previous studies (Li et al. 2016). Where quality is the parameter with the greatest improvements.

Because of the low amount of female subjects, the output results were difficult to connect to this matter. The differences in age of the subjects were also hard to connect to the output results, except in one case where a subject was 64 years of age and could not really use the AR-glasses.

The results from group B (remote guidance with AR) show that a novice takes longer time in assembling the detail and also encounters a problem in the assembling compared to an experienced worker. This might depend on that the work task is complex and needs some feel for the task performed. The fact that AR technology is a new tool for the workers can also be considered as a factor. A combination of both these factors is a considerable reason why the novices performed worse. But we are unable to know exactly what makes the assembling harder for the novice but the results points in the direction that favours the experienced worker.

Where an experienced worker lacks some sort of expertise, remote guidance with AR might be a suitable tool for the work task.

On the other hand, where a novice worker is compared between using existing instructions and remote guidance with AR, the latter shows better results in time and quality. Which is a good result in terms of the learning curve.

6.2. ADVANTAGES AND DISADVANTAGES

When the experiments were done using AR glasses, we got similar feedback from every test person. It was much clearer how the detail should be placed on the fixture, even though the camera did not have the best resolution. First time the test person did the assembly, there were a big difference it both time and quality between the techniques, which shows how much impact AR can have for a person learning a new fixture. In the future, we will also see AR devices that have a recording feature. This will help with documentation of for example a repair of a machine. It could help to prove if the repair was correctly or not. For pre-recorded instructions, developers have shown a sought feature for the device, the possibility to ask the operator if the person did the last step. If the operator checking for yes, then the instructions jump to the next step.

The disadvantages with not see-through glasses, as mentioned above in the "Practical experiments", are the feeling for distance, low contrasts, an unstable connection that made the video feed lagging and unclear picture. The glasses only had one camera; this means it only had the opportunity to display the camera footage in 2D. Not be able to see in 3D as in real life, was a big disadvantage. As the operator, you were forced to feel your way. Similar to try to find your way in a dark room. This was quite annoying and required more time to finish the assembly. The solution was to look in the glasses for the instructions, then angle away the lenses. Not an optimal solution but it helped a lot. The camera in the glasses is a bit poor. Not just the resolution was too low and had to low contrasts; it also had a narrow field of view. It made the operator turn his or her head a lot. The expert had the problem that the footage was unclear. It was not easier that the interior part and the fixture were all black. To have a stable internet connection should be of high priority when using AR. When the connection was poor, the projection in the expert's tablet tended to pixelate and gave a longer delay in the glasses. Before the experiment, the operator got the information to not turn his/her head with fast movements because it caused unclear images on the tablet.

6.3. FUTURE RESEARCH

The technology within "augmented reality" is not there yet. However, the development is quickly going forward. Soon there will be AR device with android or iOS as support platforms, which means that the device can use a phone's hardware and as a power supply. When it becomes reality, we are confident that big companies will join the scene of AR technology. Microsoft is the most well-known company that has shown its interest. They have a prototype of the glasses "HoloLens" that will be released earliest the year 2020. If the glasses work in the way they explained, the glasses will be a breakthrough for the technology. It will be exciting to see how the smaller start-up companies will manage when the worldwide companies join the branch.

6.4. IMPACT OF IMPLEMENTATION

The test results show an increasing time consumption when using AR instead of existing instructions. The case when comparing AR and existing instructions without experience is an exception. The difference is the quality, which increases drastically (Li et al. 2016). As can be seen in the test results, no details were misplaced during the assembly. This factor states the benefit with AR. The extra time during the assembly is earned in quality and with a higher quality comes lower assembly times throughout the whole assembly line. From a piece of plastic to a complete car interior. The higher quality facilitates for the buyer, in this case Volvo, which will have less trouble assembling it on the vehicle chassis.

In figure 10 (chapter 4.4.4.1), shows what happens when not experienced persons tries AR and existing instructions. In the first test, it is a big difference in times. It points against that AR can work really well as a tool to use in the first stage of learning and optionally change it for more basic instructions after a few times of assembly.

6.5. BUISNESS CASE

Longer assembly times do not need to be equal to higher costs. The higher quality can lead to fewer faults further down the assembly line or fewer reparations for the maintenance section. The results show some interesting information about the difference between the operators.

Summed up, quality is a value for costs and must be considered as one.

7. CONCLUSION

AR technology is certainly something for the future, but AR needs some further development before it can work flawlessly in industrial environments. Upgrading the design and the hardware are potentially the first steps to replace the existing ways of learning, quality check and instructions for maintenance work. We living in the perfect time for doing so. Current technologies improve faster than ever. Computers becomes smaller and smaller simultaneously as the performance improves. This will also most certain happen to AR devices when more companies join the business. The market shows tendencies to an arms race in a near future between companies that develops the technology.

Quality is clearly the most noticeable factor and it increases drastically when using the technology. AR can give instant feedback, which makes it almost impossible to do wrong and the possibility to document with recording features gives insurances. The improvement in quality can enhance collaborations between subcontractors and suppliers.

Depending on the work task, different approaches and techniques within AR can be used. Remote guidance can be very helpful in situations where a certain kind of expertise is required. The advantage with pre-programmed instructions is that it only requires one person for the work task. The bottom line is that the techniques are suitable for different types of work tasks. A company may need multiple techniques within AR to cover the whole areas of use.

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APPENDIX

APPENDIX A - SURVEY QUESTIONS

- How the learning of a new fixture does takes place?
- How many assembles requires before an employee can do it without instructions?
- Are the existing instructions used when assembly a fixture?
- Are the instructions easily accessible?
    - Should they be?
- Are the instructions well-structured and easy to understand?
- Can the existing instructions be improved?
    - How?
- What kind of errors can occur during a fixture assembly?
- Which error is most common?
- How are errors detected? At the assembly or at the measurement control?
- How are assembly errors fixed?
- What kind of complications does the errors leaves?

APPENDIX B – SURVEY QUESTIONS BEFORE ASSEMBLY

- How old are you?
- Male or female?
- Have you worked with another fixture before?
- Do you have earlier experience of assembles?
- What is your employement?

APPENDIX C – INTERVIEW QUESTIONS (EXISTING INSTRUCTIONS)

- Did you assembled something wrong?
- Why did you assembled it right/wrong?
- Were the existing instructions helpful?
- Were the instructions easy to understand?
    - If no, how can they be improved?
- Had you preferred assistance of an expert, image instructions or text instructions?
    - Why?

APPENDIX D – INTERVIEW QUESTIONS (GLASSES)

- Did you assembled something wrong?
- Why did you assembled it right/wrong?
- How was the experience of AR technology?
- Were the instructions easy to understand?
    - If no, how can they be improved?
- What kind of advantages and disadvantages is there with AR glasses?
- Would you consider using similar instructions for future work tasks?
- Do you think the technology has potential?

APPENDIX E – EXISTING INSTRUCTIONS