Augmented Reality at the Industrial Shop-Floor

Anna Syberfeldt, Oscar Danielsson, Magnus Holm, Tom Ekblom

Virtual System Research Centre, University of Skövde, Skövde, Sweden
anna.syberfeldt@his.se

Abstract. This paper describes a study of the potential of using augmented reality at the industrial shop-floor with the aim of improving the capability of the shop-floor operators. In the study, a prototype system for augmented reality is developed based on the Oculus Rift platform. The system is evaluated through an experiment in which a physical three-dimensional puzzle is to be assembled.

Keywords: augmented reality, industrial shop-floor, assembling, oculus rift.

1 Introduction

Manufacturing companies of today face a global and rapidly changing market. To stay competitive, it is of critical importance for companies to continuously improve their shop-floors. A powerful, yet extensively overlooked, mean to improve shop-floor performance is to enhance the capability of its operators. In their daily work, shop-floor operators constantly face complex and uncertain situations due to unpredictable events and uncontrollable variations (such as machine breakdowns, fluctuating product demand, re-prioritizations, etc.). There is a need of finding new methods and tools that increase productivity and quality by supporting the operators in making the right decisions and optimally operating the shop-floor.

This paper describes a study of improving the capability of shop-floor operators by using augmented reality. With augmented reality, artificial information about the environment and its objects can be overlaid on the real world in order to enhance the operator's perception of reality. Augmented reality is today mainly used in application areas such as gaming, sports and tourism. The topic has also recently begun to be discussed within the context of industrial shop-floors, but so far mainly as a concept and there exist few practical demonstrators. This study aims to advance the research on augmented reality within the manufacturing domain by developing a prototype system. The study is part of the research project "Young Operator 2020" at the University of Skövde in Sweden. The aim of this project is to technically improve the industrial shop-floor and provide industrial operators with better tools in order to support the operators in making the right decisions and work optimally. The authors are certain that augmented reality is a key to fulfill this aim, and also that the technique will be part of all modern, high-tech shop floors of the future. This idea is also supported by previous studies of using augmented reality within industry, see for example Henderson and Feiner (2009) and Henderson and Feiner (2011).

adfa, p. 1, 2011.

The next section continues by describing the approach used in the study for implementing augmented reality. In Section 3, the equipment developed in the study is presented, followed by a description of the experiment performed in Section 4. In Section 5, results from the experiment are discussed. Section 6, finally, outlines conclusions from the study and possible future work.

2 Approach for implementing augmented reality

There exist a number of methods to implement augmented reality. Krevelen and Poelman (2010) divides the various implementations into three general categories: a) hand-held, b) head-worn, and c) spatial. Head-worn implementations are in turn divided into retina projection, optical, video and projective. Spatial implementations are also divided into sub-categories: video, optical and projective. In this study, a head-worn implementation is selected. This is since such implementation frees the user's hands, which is seen as a necessary feature when considering shop-floors. It could be noted that a spatial implementation also frees the user’s hands, but as this implementation requires fixed equipment in the working environment (Krevelen and Poelman, 2010) it is considered as too inflexible.

For realizing the head-worn implementation in the study, the choice stood between a video-based solution and an optical solution (retina projection and projective solutions were not considered for practical reasons). Rolland and Fuchs (2000) describe the trade-off between optical and video-based solutions in the following manner:

“Optical see-through HMDs take what might be called a ”minimally obtrusive” approach; that is, they leave the view of the real world nearly intact and attempt to augment it by merging a reflected image of the computer-generated scene into the view of the real world. Video see-through HMDs are typically more obtrusive in the sense that they block out the real-world view in exchange for the ability to merge the two views more convincingly.” (Rolland and Fuchs, 2000, page 293)

Both solutions clearly have advantages, and in selecting between them the decisive factor was set to image updating performance at head moves. This is considered important as an industrial operator will move frequently and not seldom rapidly. Jeon and Kim (2008) have performed studies on head movements and they found that the slowest head moves correspond to an angular velocity of 8 degrees per second, while the fastest were up to 80 degrees per second. Jeon and Kim (2008) also found that in approximately 95% of the cases the users rotated their heads with a speed of approximately 40 degrees per second. In a similar study, Azuma (1997) found that the average speed of moving the head was 50 degrees per second. With a latency of 100 milliseconds in a system, Azuma (1997) state that the dynamic error is about 5 degrees. At a distance of 68 centimeters this accumulates to an error of 60 millimeters. Considering these findings, it is obvious an optical solution where the virtual information is projected directly on the real world objects, even normal head moves will require an extremely fast and frequent image updating in order to avoid visual lag. Visual lag is caused by, for example, communication or rendering delays and means that the virtual objects do not stay in the correct real-world position when the user moves. To avoid the problem of lag, a video-based solution is chosen in the study. With this solution, the real world and the virtual world are merged into the same view, and the user's view is completely digital. In this way, the real world and the virtual world can be easily synchronized. A video-based solution is, however, far from perfect as there will always be a mismatch between what the user sees and what is happening in the real-world. This is since the process of capturing the video stream, convert it into digital format and rendering it on a screen impossibly can be made at the speed of light. This means that there is always a delay of the user’s sight which might cause body coordination problems.

In the next section, the equipment used to implement the video-based solution is described.

3 Equipment

The hardware platform used in the study is the first version of Oculus Rift (http://www.oculusvr.com/), see Figure 1. The Oculus Rift is selected since it is easy to work with, comes with a low price and is available on the public market.

Fig. 1. Oculus Rift.

Since Oculus Rift is developed for virtual reality where the real-world is totally blocked-out, modifications are needed for using it for augmented reality. Such modifications have previously been made by Steptoe (2013). Steptoe mounted two web cameras in front of the Oculus Rift and showed their video streams on the Oculus's screens. With such solution, one achieve video-based, digital view of the real world on which it is possible to place virtual objects. The same solution as proposed by Steptoe is used also in this study.

The modified Oculus Rift used in the study is shown in Figure 2. As can be seen in the picture, there are two sets of a bowed aluminum plates that can be slipped on from the side. These make it possible to adjust the cameras laterally which is important in order to compensate for different users having different distances between their eyes. Each aluminum plate has three holes in it and each hole has a nut screw. The screws are used to hold a plastic disc on which the cameras are glued. The plastic discs can be adjusted laterally by tightening or loosening the screws. For each screw hole in the plastic disc, there is a 25 mm slits that allows adjusting the cameras in height. adjusting the cameras in height as this has been considered as important in previous studies by Park et. al. (2008). Park et al. studied the effect of eye-hand coordination with different camera positions. They tested a number of different positions and found that a height displacement of 35 mm above or below the eyes gave a better user experience compared to when the cameras were placed at eye level.

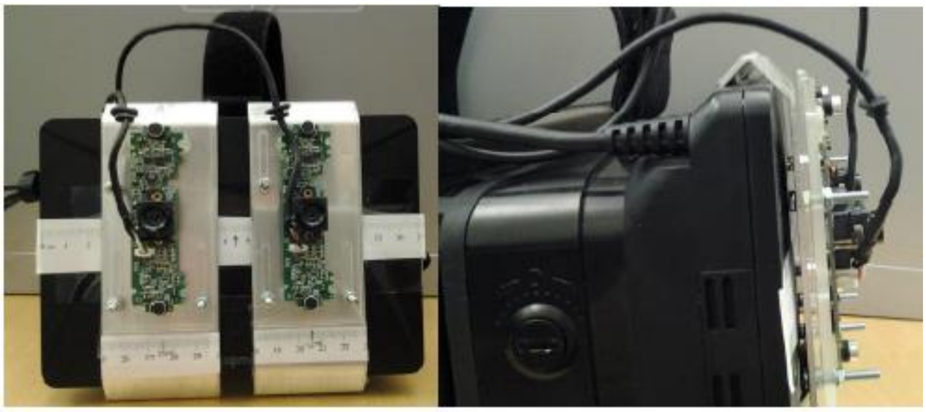


Fig. 2. Cameras mounted on Oculus Rift.

The next section describes how the modified Oculus Rift has been used to in an experiment meant to imitate an industrial assembling process.

4 Experiment

As the study aims to investigate the use of augmented reality for aiding industrial shop-floor operators, a scenario imitating an industrial assembling process is set up. In this scenario, the task of the user consists of assembling a three-dimensional puzzle with nine pieces (see Figure 3). The pieces are to be placed in a certain order and at specific positions, just like in industrial assembling. Similar assembling tasks for studying augmented reality have previously been used by Sääski et al. (2008) and Woodward et al. (2012).

When undertaking the assembling of the puzzle, the user wears the modified Oculus Rift. The user then sees the real world digitally and virtual information is added on physical objects, creating an augmented reality effect. For handling the virtual information a library called Metaio is used (www.metaio.com).

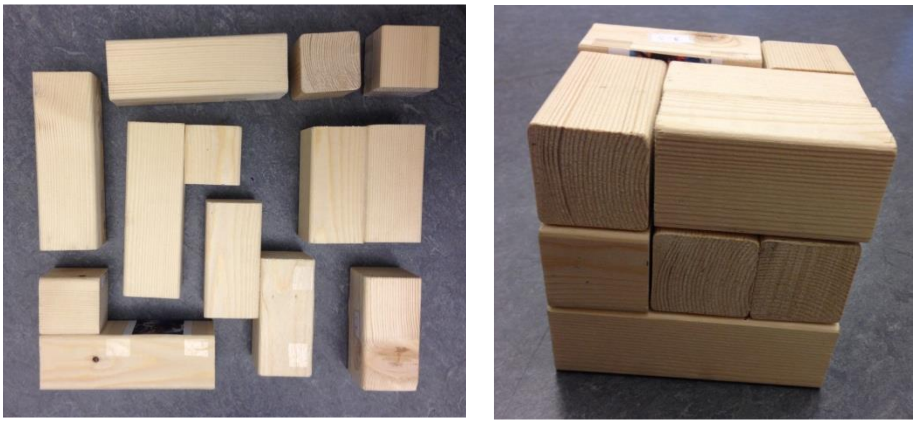


Fig. 3. Three-dimensional puzzle used in the experiment.

At the Oculus's screens, the piece to select next is highlighted in green and the place to put it is marked with the same shape and color. Figure 4 presents a screenshot illustrating the effect. In the screenshot, the user holds piece number one, which is overlaid with green color and pointed on with a virtual arrow. The piece is to be placed at the position marked with the same shape, color and number as the piece itself. As a the reference for determining positions of objects a reference image is used. In this case, the reference image is a photo of a team of budo girls as can be seen in the screenshot. A full demonstration of the augmented reality function and a complete assembling of the puzzle can be found at http://youtu.be/tuP28sZ6EZM.

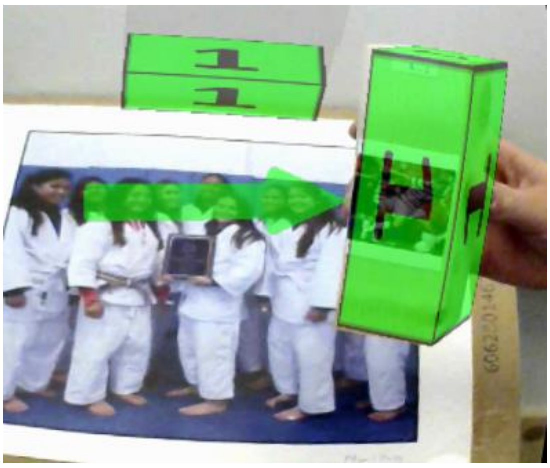


Fig. 4. Screenshot from Oculus's screen.

In the study, six persons were participating in the experiment and given the task of assembling the puzzle wearing the modified Oculus Rift. The participants were given a short introduction to the task before starting, but did not receive any information about the equipment. During the assembling, there was no guidance given except in the case that a participant asked for it (which happened twice). After the assembling was completed, the participant was asked to fill in a questionnaire in order to assess their experience. The questionnaire was developed based on the questionnaire used in Looser et. al (2007) and consists of the following seven questions, each to be graded on a Likert scale from 1 to 7 (1 = totally disagree, 7 = totally agree):

Question 1: I found the system easy to understand.

Question 2: I found it easy to place a piece of the puzzle.

Question 3: I felt like I performed efficient with this system.

Question 4: If I had to use equipment like this on a regular basis, I would appreciate having access to.

Question 5: I found the system physically exhausting.

Question 6: I found the system mentally exhausting.

Question 7: I found the system frustrating.

In the next section, results from the experiment are presented in the next section.

5 Results

All six participants succeeded in assembling the puzzle, but needed different amounts of time for carrying out the task. The fastest assembling was performed within 3 minutes and 37 seconds, while the slowest assembling took about three times as long - it was completed within 10 minutes 30 seconds. The significant difference in amount of time needed for carrying out the task indicates a spread among the participants regarding their ability to adapt to the equipment and/or their previous experience in handling this type of technology. A familiarity with the equipment being advantageous becomes clear when studying the time consumption of individual pieces. As shown in Figure 5, the first two pieces took considerable longer time to place correctly compared to the rest.

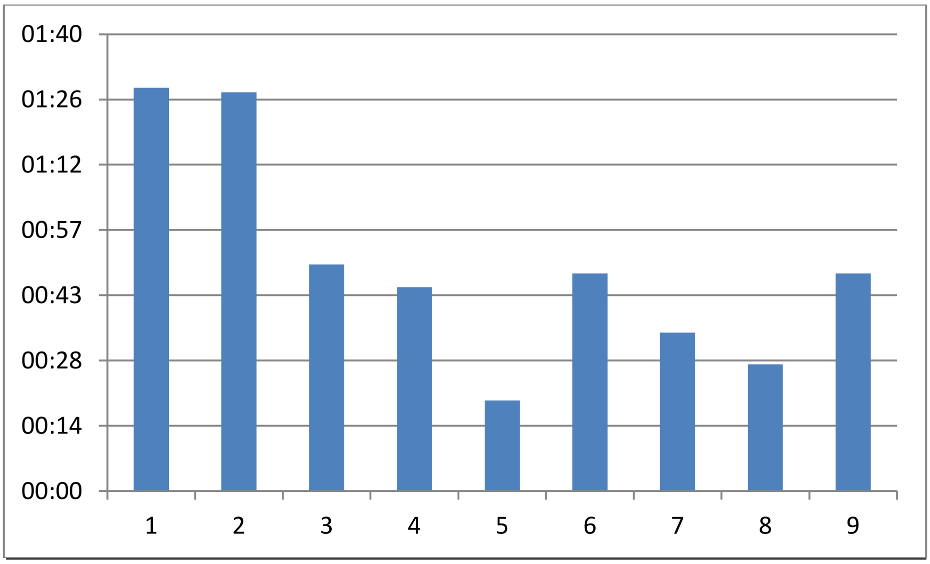
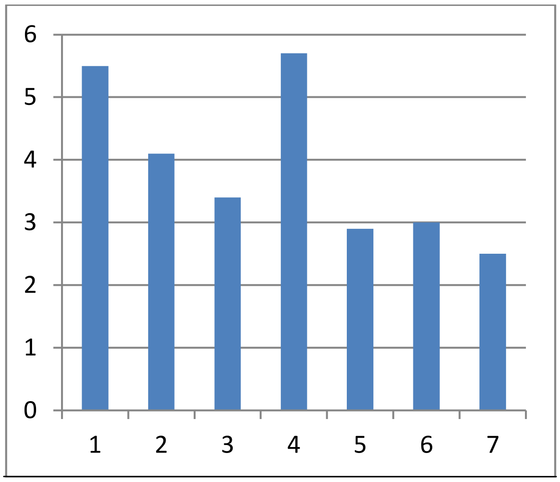


Fig. 5. Time consumption of each of the nine pieces of the puzzle (average values).

After placing the first two pieces of the puzzle, the test participants had learned the basics of how to use the equipment and were able to perform faster. The single most important aspect for the participants to learn in order to perform the task efficiently was to retain the reference image (the photo of the budo girls) in the camera's field of view. When the reference image gets out of sight, no virtual information can be shown and the user then gets completely lost. All of the participants in the experiment experienced this a couple of times, especially with the first two pieces before learning how to avoid it.

Although there was a learning curve for the participants, all of them considered the system easy to understand as shown in Figure 6 were average results from the questionnaire are presented. Furthermore, the participants thought that they would appreciate having access to system like this it if faced with a work task that needed it. However, as also can be seen in the figure, the participants experienced that the system was both physically and mentally stressful, and also that it made them frustrated to some extent. The main cause mentioned for the negative experience was the heavily deteriorated vision that followed by using the equipment. In fact, this is no surprise since the resolution of the Oculus Rift's screens is only 640 x 800 pixels. The user cannot only see the individual pixels, but the pixels are also placed with a small gap between them. The result is a quite blurry sight with a black grid net laid upon everything the user sees, which is disturbing. Furthermore, the sight angle is significantly reduced as the angle of the web camera (which is used record the real-world) is limited.



Q1: I found the system easy to understand.
Q2: I found it easy to place a piece of the puzzle.
Q3: I felt like I performed efficient with this system.
Q4: If I had to use equipment like this on a regular basis, I would appreciate having access to.
Q5: I found the system physically exhausting.
Q6: I found the system mentally exhausting.
Q7: I found the system frustrating.

Fig. 6. Questions and average results (1 = totally disagree, 7 = totally agree).

In the next section, conclusions from the experiment is outlined and future work is discussed.

6 Conclusions and future work

This paper described a study of using augmented reality for aiding the user in an assembling process. The aim of the study was to investigate the potential of using augmented reality at the industrial shop-floor in order to improve the capability of the shop-floor operators. In the study, a prototype equipment was developed based on the Oculus Rift platform. The prototype was evaluated in an experiment in which the participants were presented with the task of assembling a physical three-dimensional puzzle.

Results from the experiment showed that the participants were guided by visual information in the assembling process and were able to successfully assemble the puzzle. An important point to raise is that with the system, the participants were not able to move on with the puzzle in case a piece was not correctly placed. This type of built-in control helps to protect against human error and is very valuable in industry. In general, the participants believed that augmented reality was easy to grasp, but they experienced considerable mental and physical stress during the experiment. This negative experiences were mainly connected to the heavily reduced sight that comes with the Oculus Rift. However, it is important to keep in mind that the Oculus Rift at the moment is at a very early stage and that it will have considerable better screen resolution and refresh rate when released as a commercial product. The next version of the Oculus Rift is coming already in 2014 with a screen resolution of 960 x 1080 pixels, and the commercial version coming later on will have even higher resolution. As the technology advances, the user experience will increase significantly.

However, in an industrial setting the Oculus Rift, or any video-based solution for augmented reality, will most probably not be useful. This is since the industrial shop-floor is generally a high-risk environment with automated machines, robots, trucks, chemicals, etc. With a video-based solution the operator's sight is completely digitized and technology-dependent, which is too risky in case of, for example, a power failure in the equipment. However, while waiting for the head-worn solutions for augmented reality to become further developed and available at the market (for example, Google glasses), the video-based approach is perfectly fine to use for experimenting in safe environments.

In the near future, the authors intend to assess the actual improvements gained by using augmented reality in comparison with not doing so. This can, for example, be done by using the same task of assembling the three-dimensional puzzle but only letting the participants use paper instructions for how to place the pieces. For comparative results, differences in time consumption and error rates should be measured. Extensions of the study could also preferably involve a larger number of participants and several other assembling tasks with higher complexity. If possible, it would be advantageous to study ergonomic aspects as part of such extended study, for example related to head and hand movements. Body coordination with and without equipment would also be interesting to investigate.

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