Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 44 (2016) 108 – 113

www.elsevier.com/locate/procedia

6th CIRP Conference on Assembly Technologies and Systems (CATS)

Support systems on the industrial shop-floors of the future – operators' perspective on augmented reality

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

[a]*University of Skövde, PO 408, SE-54148 Skövde, Sweden.*
[b]*Royal Institute of Technology, PO-1148, Stockholm, Sweden.*
[c]*Volvo Cars Engine, Skövde, Sweden.*

* Corresponding author. Tel.: +46(0)500448577. *E-mail address:* anna.syberfeldt@his.se

Abstract

With augmented reality, virtual information can be overlaid on the real world in order to enhance a human's perception of reality. In this study, we aim to deepen the knowledge of augmented reality in the shop-floor context and analyze its role within smart factories of the future. The study evaluates a number of approaches for realizing augmented reality and discusses advantages and disadvantages of different solutions from a shop-floor operator's perspective. The evaluation is done in collaboration with industrial companies, including Volvo Cars and Volvo GTO amongst others. The study also identifies important future research directions for utilizing the full potential of the technology and successfully implement it on industrial shop-floors.

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)

Keywords: Augmented reality; industrial operators; shop-floor.

1. Introduction

The concept "smart factory" is popularly used when discussing what factories in the future will look like. In a smart factory, machines and products act intelligently and everything in the factory, including the humans, are connected to the Internet and share information with each other [1]. In the smart factory, the product itself carries information about when, where and how it should be manufactured. The smart factories aim at high flexibility with adaptable production processes that are able to deal with short product life-cycles and extreme customization in a cost-efficient way [2]. The paradigm shift coming with the smart factories will significantly change the way production is undertaken and thereby also the work environment for operators at the shop-floors. The new way of working will require that the operators are equipped with efficient support systems that aid them in making the right decisions and act optimally in a constantly changing work environment. The decision support systems must operate in real-time and ensure that the operators always have the right information at the right time and the right place. A technology being discussed more and more in the research community for implementing decision support systems of the future is "augmented reality" [3]. 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, and the topic has also begun to be discussed within the context of industrial shop-floors. In this study, we aim to deepen the knowledge of augmented reality in the shop-floor context and analyze its role within smart factories of the future. The study evaluates a number of approaches for

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)
doi:10.1016/j.procir.2016.02.017

realizing augmented reality and discusses advantages and disadvantages of different solutions from a shop-floor operator's perspective. The evaluation is done in collaboration with industrial companies, including Volvo Cars and Volvo GTO amongst others.

The next chapter continues by discussing the shop-floor operator further and gives an overview of the historical and future development. In Chapter 3, augmented reality is described in further detail. Chapter 4 presents the evaluation of various solutions for augmented reality in the context of the industrial shop-floor. In Chapter 5, conclusions from the study are outlined and future research directions are discussed.

2. The development of the shop-floor operator

To understand the shop floor operator of the future, it is relevant to first look back in time. Holm et al. [4] describe the historical development of the industrial operator with a focus on work environment as well as on knowledge demands. Holm et al. have performed an extensive study on six Swedish manufacturing companies and interviewed managers both within production and at the HR departments. Since manufacturing in Sweden is similar to manufacturing in industrial countries in general and since several of the companies are multi-national, it is reasonable to expect that the results are generally applicable to many manufacturing companies. In fig. 1, characteristics of the work environment and the requirements for a typical shop-floor operator during the first half of the 1900s are presented. During this period, the operator was more or less considered to be a machine that needed structure and strict guidance to work effectively. Intelligence or deep knowledge was not asked for, neither was it needed as decisions were taken by higher-level managers.

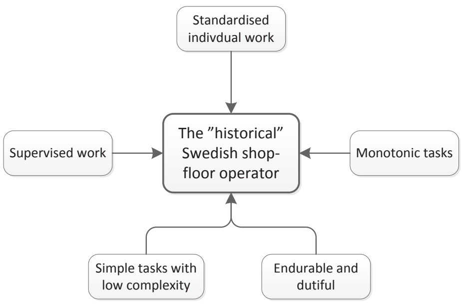

Fig 1. The historical operator (adopted from Holm et al., 2014).

In the 1980s, the philosophies of Toyota Production System (TPS) and Total Quality Management (TQM) were spread and along with these a focus on flexibility, quality and customer needs. As a consequence of this, the role of shop-floor operators changed and the modern operator was formed (fig. 2). Compared to earlier, the operator is now supposed to be able to undertake more sophisticated tasks and make own decisions. The Lean principles (such as continuous improvements and waste elimination) have influenced, and still influences, the daily life of an operator.

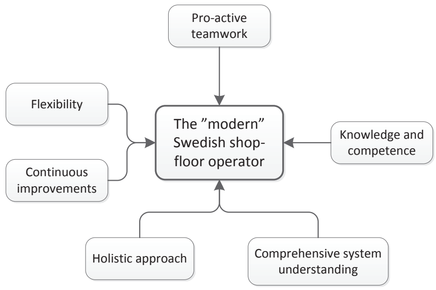

Fig 2. The modern operator (adopted from Holm et al., 2014).

Looking into the (near) future, the work environment of shop-floors and the requirements of their operators will continue to change in an increasingly higher pace. Fig. 3 illustrates expected knowledge and skills of the future's operators in the smart factories, and it is clear that a big leap is coming. For the operators to be ready for this leap, the development of efficient decision support systems are of uttermost importance as previously discussed.

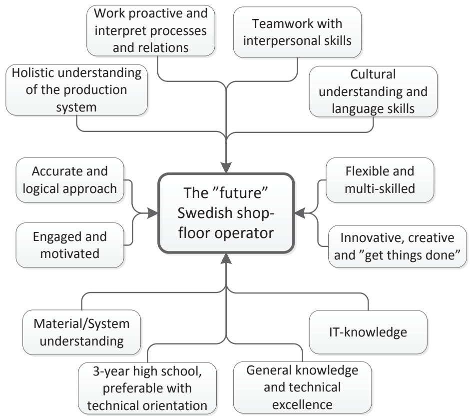

Fig 3. The future operator (adopted from Holm et al., 2014).

3. Augmented reality

The term augmented reality was introduced by Caudel and Mizell [5] to denote a heads-up, see-through display that they had designed. Caudel and Mizell stated that "*This technology is used to "augment" the visual field of the user with information necessary in the performance of the current task, and therefore we refer to the technology as "augmented reality*." (p.660). Azuma [6] state that augmented reality is a system having three characteristics: the ability to combine real and virtual objects, the ability to be interactive in real-time, and the ability to use 3D objects. It is important to note that augmented reality includes more senses than the visual, it can potentially apply to all senses, including hearing, touch and smell [7]. A recent definition of augmented reality is provided by Kipper and Rampolla [8]:

"Augmented Reality (AR) is a variation of a Virtual Environment (VE), or Virtual Reality (VR) as it is more commonly called. Virtual Reality technologies completely immerse a user inside a synthetic environment and while immersed, the user cannot see the real world around him. In contrast, Augmented Reality is taking digital or computer generated information, whether it be images, audio, video and touch or haptic sensations and overlaying them over in a real-time environment." (p. 1).

Augmented reality is generally implemented through some form of anchor in the real world that is used for navigation. The most common form of anchor is a specific pattern image, and by connecting virtual objects to pattern images it becomes possible to orientate and correlate virtual objects to objects in the real world. For the user to interact with the augmented reality systems a display of some kind is used. There are basically three types of displays that can be used: a) hand-held, b) head-worn, and c) spatial [9]. 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. An overview of display types and the most common type of hardware used is given in fig. 4 below.

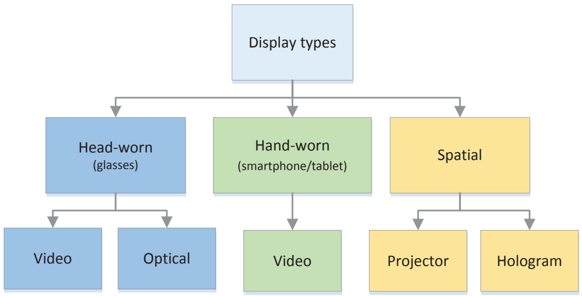

Fig. 4. Different types of displays and hardware used for augmented reality.

The different types of displays and hardware used to realize augmented reality have different strengths and weaknesses depending on the application purpose. In the next chapter, the different solutions are evaluated in the context of the industrial shop-floor and from an operator's perspective.

4. Evaluation of different solutions for augmented reality from a shop-floor operator's perspective

The evaluation of different solutions for augmented reality is based on prototype implementations of the different display types presented in Figure 4. One prototype for each display type is developed, except hologram which is considered far too expensive to implement. This means that four prototypes are developed to be used in the study:

- Prototype #1: Video-based glasses
- Prototype #2: Optical glasses
- Prototype #3: Video-based tablet
- Prototype #4: Spatial projector

Some of the prototypes are fully functional systems, while others are static without real functionality (but do still realistically representing a real system). All prototypes are designed for an industrial scenario in order to make sure that the evaluation is relevant from an industrial perspective. The scenario used varies between the prototypes as different solutions are suitable for different purposes. For each prototype, a scenario expected to be appropriate for that specific solution is selected.

For the evaluation of the different solutions, workshops and interviews with representatives from manufacturing companies within West Sweden is performed. Seven companies are involved, including Volvo Cars, Volvo GTO, Daloc, Swegon, Vici Industrier, Elektroautomatik and Coors. The degree of involvement varies between the companies while the two Volvo companies represent the most extensive involvement. During the workshops and/or interviews, the prototypes are demonstrated to the participants and they are given the possibility to try them out. The participants are asked to share their thoughts and opinions about the different solutions and these are presented in the following of this chapter.

4.1 Prototype #1: Video-based glasses

With a video-based 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. For realizing a video-based prototype, the Oculus Rift platform is being used (http://www.oculusvr.com/). 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 [10]. 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 achieves 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 5 below.

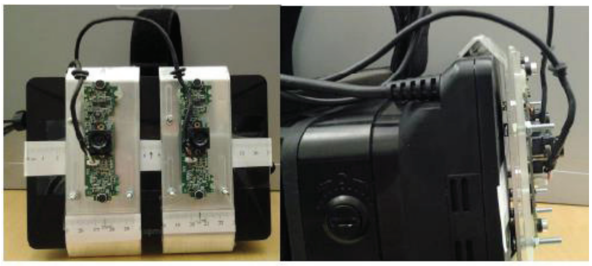
Fig. 5: Video-based prototype in form of a modified Oculus Rift.

A scenario imitating an industrial assembling process is set up in which a three-dimensional puzzle is to be assembled. Instructions on how to perform the assembling and where to place each piece of the puzzle in relation to the other pieces are given on the Oculus's screens. Experiences from using the prototype are summarized below in the form of advantages and disadvantages expressed by the participants.

Advantages

- The operator’s hands are free.
- No problem of visual lag as the real view and the virtual view is merged into the same view.

Disadvantages

- Heavy to wear.
- There is a mismatch between what the user sees and what is happening in the real-world, which might cause body coordination problems.
  Authors comment: Since the process of capturing the video stream, converting it into digital format and rendering it on a screen can impossibly be made at the speed of light, there will always be a delay of the user's sight.
- 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. The industrial shop-floor is generally a high-risk environment with automated machines, robots, trucks, chemicals, etc.

4.2 Prototype #2: Optical glasses

Optical solutions leave the view of the real world nearly intact and overlay virtual object on the view of the real world. In the study, we have used the glasses C-Wear from Penny (www.penny.se/) to implement a prototype for evaluating optical glasses (Figure 6). Several similar optical glasses exist as off-the-shelf products, including for example Epson glasses (www.epson.com). The C-Wear glasses are connected to a portable, Android-based device and the augmented reality functionality is implemented at this device. In the Android-based device, we use a general software library for augmented reality previously developed by the research group. This library use Vuforia for realizing the AR functionality. Vuforia is a software development kit (SDK) for mobile devices that supports the creation of augmented reality application. The SDK implements vision technology to recognize and track image targets and simple 3D objects in real-time. With the image recognition feature it is possible to position and orient virtual objects in relation to real world objects when these are viewed through the camera of a mobile device. The virtual object tracks the position and orientation of the image in real-time so that the viewer’s perspective on the object corresponds with their perspective on the image target. In that way, it appears that the virtual object is a part of the real world. More information about Vuforia can be found at www.qualcomm.com.

In the study, a scenario imitating a final inspection of an engine at Volvo Cars is set up in which the operator is to control a number of aspects of a partly finished engine (Figure 6). What aspects to control and the exact location of the details to control are shown in the glasses.

Fig. 6. Operator using the prototype implementation of optical glasses.

Experiences from using the glasses are summarized below.

Advantages

- The operator’s hands are free.
- The view of the real-world is almost intact.
- Perceived efficiency increase in performing the task.

Disadvantages

- Image updating at head moves sometimes lag behind.
  Authors comment: The visual lag is caused by communication and/or rendering delays and means that the virtual objects do not stay in the correct real-world position when the user moves. Even normal head movements require an extremely fast and frequent image updating in order to avoid visual lag, which is not possible to ensure even with the newest hardware technology.
- Difficult to use the glasses if already wearing (ordinary) glasses.
- Heavy to wear after a while.

4.3 Prototype #3: Video-based tablet

An optical tablet utilizes the camera in combination with the same approach as the optical glasses uses for overlaying virtual object on the view of the real world (the view of the real world is captured using the camera of the tablet). For the prototype implemented in the study, an Android-based Nvidia SHIELD tablet with a 9” screen is used. The tablet implements the exact same software library as used in prototype #2 for realizing augmented reality. The scenario set up in the study mimics a real quality control station at Volvo GTO. At the station, the operator is to undertake a number of different tasks related to controlling the quality of an engine block. In the tablet, instructions for the different tasks are shown in the form of text, pictures and virtual objects. A screen shot from the user interface of the prototype is shown in Figure 7 below.

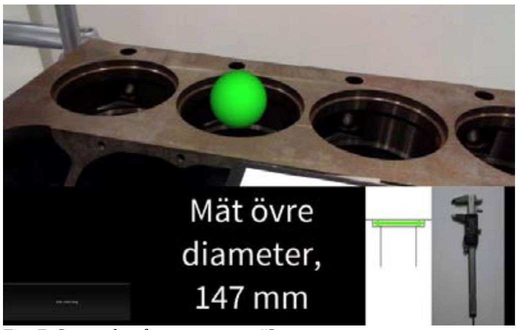

Fig. 7. Screenshot from prototype #3.

Experiences from using the tablet are summarized below.

Advantages

- High familiarity – almost everybody is used to tablets nowadays.

Disadvantages

- Either occupies the operator's hands or, if placed in a stand, must be constantly re-located for being in the operator's field of view and is often in the way.
- If the operator's hand or a tool comes in the way of the camera the virtual objects disappear.
  Authors comment: This happens since the pattern image is covered which is used as an anchor for the augmented reality system. The virtual objects disappear when the image disappears as the augmented reality system has no idea of where to place objects.

4.4 Spatial projector

Spatial implementations of augmented reality detach the display from the user and instead integrate it into the environment. The most common way to realize a spatial implementation is through a projector, which is also the approach used in the implemented prototype. The prototype is developed for, and tested on, one of Volvo GTOs engine block. An ordinary projector is used which is mounted next to the engine block. When used in full daylight, the colour intensity and sharpness of an ordinary projector are not perfect and advanced graphical objects must therefore be avoided in the augmented reality system. Therefore, a scenario is set up in which one-coloured text is constituting the major part of the system, see fig. 8. Typical paper-based instructions are transformed into projection-format and the instructions are projected either directly on the engine if enough space at the area of interest, and otherwise on a small plate just behind the engine block. The projector is also used to direct the operator's focus on specific parts of the engine by using dot points. Experiences from using the prototype are summarized below.

Fig. 8. Screenshot from prototype #4.

Experiences from using the tablet are summarized below.

Advantages

- The operator's hands are free,
- Does not directly affect the operator's sight,
- The operator does not need to carry anything,

Disadvantages

- Requires hardware equipment to be permanently installed in the working environment, which is inflexible and might also be expensive.
- If something (the operator, a tool, etc.) comes in the way of the projection, the information becomes invisible.

4.5 General opinions

Almost all participants thought that the prototypes were easy to understand and easy to use, although they were completely new to the technology. This is very positive since easy-of-use is an important factor for acceptability and a necessity for the success of augmented reality on the shop-floors. Another positive aspect is that most participants perceived increased efficiency with augmented reality. Several participants, however, expressed that perceived efficiency it not enough – the increase in efficiency with augmented reality must be really proved for widespread acceptance. It must be proved that augmented reality makes the user more efficient, otherwise the user will see no sense in using the technology. Furthermore, the complexity of the task must be high enough for the operator to feel that it is worth using the augmented reality system. Preferably, the task should be so hard that it is almost impossible to complete without the system, at least for a junior operator.

5 Conclusions and future research directions

The smart factory of the future will significantly increase the demands on the shop floor operators' skills and knowledge. Augmented reality is a powerful technology for aiding the operators in the smart factory, and the technology will certainly be an integrated part of factories of the future. The strength of augmented reality is the possibility to give the operators access to information that their ordinary senses could not have gathered from reality, and to give this information in the context of where it is needed. Although augmented reality is very promising, we believe that there is a lot of research still remaining in order to utilize the full potential of the technology and successfully implement it on the shop floor. Below, we outline what we see as the major challenges and the topics that we believe are important to focus on within the research community.

5.1 Privacy

For a decision support system realized using augmented reality to work properly it must keep track of what the operator is doing and seeing. This mean that the system constantly monitors the operators' whereabouts and it can be argued that the integrity of the operator is breached. To safeguard the operator's integrity there needs to be a great awareness of what data is being logged and for what purpose. Even so, one should be aware that data often can be used for other intents than the original. Therefore we recommend investigating general policies regarding what data should be collected, how it should be stored and for how long, who should have access to it and for what purpose.

5.2 Data security

One of the great strengths of smart factory is the fact that virtually everything is connected and communicates with each other (according to the concept "Internet-of-Things") – including also the augmented reality systems. This strength is, however, at the same time a great weakness from a safety perspective. Sensitive data regarding both individual operators and confidential business operations are send over networks and it is crucial that it is protected from third party access. Encryption and security certificates are efficient to protect eavesdropping and hostile acts. How to integrate such preventive security measures in decision support systems using augmented reality is, in our opinion, important to investigate.

5.3 Information content

The information provided to an operator in a decision support system using augmented reality must depend on the previous experience and skills of the individual operator in relation to the work task at hand. We believe that the information content should be dynamically customized for augmented reality, and hence also the operator, to be effective. Dynamically customizing instructions for individual operators is, however, no easy task. For each task and operator it must be decided in real-time what information is important to show at the moment and in which form, as well as what information *not* to show. The latter is important since too much information is not only frustrating for the operator, but might even be detriment due to the high cognitive load imposed. These aspects related to information content, we believe, need to be further studied.

5.4 Location awareness

For successfully using augmented reality and providing the operators with right information at the right time, a real-time localization system is necessary that keeps track of current position of all individual operators. With such system, it is also possible to realize the previously described location-aware work instructions with dynamically adjusted content for a specific operator being at a specific location. There are several commercial indoor localization systems on the market utilizing different solutions, but a quick review of these shows that none of them seem to specifically target industrial shop-floors. Shop-floors, we argue, need customized indoor localization systems that explicitly consider industrial characteristics such as spacious buildings, lots of metal, dirt and dust, many moving objects, heavy network traffic, etc. for achieving a high enough accuracy. Only if the precision in the positioning of the operator is almost perfect the integration with augmented reality can be successful.

5.5 Tailor-made solutions for human-robot collaboration

In the smart factory, a closer interaction between human and automation, especially between human and robots, are expected. By combining the best qualities of a human, such as sensibility, flexibility and high intelligence, with the best qualities of a robot, such as strength and durability, new and improved ways of working can be realized [11]. However, a closer integration between human and robot requires new types of decision support systems specifically designed for such interaction. Augmented reality is certainly suitable for this and can be used not only for real-time interaction, but also for example for robot programming. How to design augmented reality systems for the purpose of human-robot collaboration is an important topic for future research.

References

[1] Zuehlke, D. (2010). SmartFactory—Towards a factory-of-things. Annual Reviews in Control, 34(1), 129-138.

[2] Veza, I., Mladineo, M., & Gjeldum, N. (2015). Managing Innovative Production Network of Smart Factories. IFAC-PapersOnLine, 48(3), 555-560.

[3] Kolberg, D., & Zühlke, D. (2015). Lean automation enabled by industry 4.0 technologies. IFAC-PapersOnLine, 48(3), 1870-1875

[4] Holm, M., Adamson, G., Wang, L., & Moore, P. (2014, November). The future Swedish shop-floor operator. In The 6th Swedish Production Symposium.

[5] Caudel, T. & Mizell, D., (1992) Augmented Reality: An Application of Heads-Up Display Technology to Manual Manufacturing Processes. Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences (HICSS). Volume II, p. 659-669.

[6] Azuma, R. (1997) A Survey of Augmented Reality. Malibu, Hughes Research Laboratories.

[7] Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S. & MacIntyre, B. (2001) Recent Advances in Augmented Reality. Computer Graphics and Applications, IEEE. 21 (6), p. 34-47.

[8] Kipper, G. & Rampolla, J. (2012). Augmented Reality: An Emerging Technologies Guide to AR. 1st Edition, Syngress. ISBN: 9781597497343.

[9] Krevelen, D. and Poelman, R. (2010) A Survey of Augmented Reality Technolo-gies, Applications and Limitations. The International Journal of Virtual Reality. 9 (2), s. 1-20.

[10] Steptoe, W (2013) AR-Rift: Stereo camera for the Rift & immersive AR show-case. Oculus Developer Forums. Available on Internet: https://developer.oculusvr.com/forums/viewtopic.php?f=28&t=5215 [retrieved November 25, 2015].

[11] Michalos, G., Makris, S., Spiliotopoulos, J., Misios, I., Tsarouchi, P., & Chryssolouris, G. (2014). ROBO-PARTNER: Seamless Human-Robot Cooperation for Intelligent, Flexible and Safe Operations in the Assembly Factories of the Future. Procedia CIRP, 23, 71-76.