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Testing and validating Extended Reality (xR) technologies in manufacturing

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Abstract

xR technologies such as Augmented Reality (AR) and Virtual Reality (VR) are increasing at shop-floors but are still in need for validation in order to make good strategic decisions regarding implementation. The areas where most industries apply AR is within remote guidance and complex tasks such as maintenance. VR is mostly used for layout planning and more and more for virtual training. This paper aims to present results from six case studies with over two hundred responders from academy and industry about usage and strategies on where and when to implement what xR technology..

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Keywords: AR;VR; cyber-physical; information levels, utilization, CPPS-testbed; learning factories.

1. Introduction

Digital manufacturing has been considered, over the last decade, as a highly promising set of technologies for reducing product development times and cost as well as for addressing the need for customization, increased product quality, and faster response to the market [1]. Bridging of digital/cyber/virtual and physical worlds can mean a lot of time savings in almost all areas in manufacturing i.e. design [2], prototyping [3], learning, marketing, logistics [4], maintenance [5], set-ups, remote guidance, assembly etc. Technologies like xR (i.e. ***A***ugmented, ***M***ixed and ***V***irtual Reality) could be useful in order to accomplish this bridge but also to increase time-room flexibility i.e. the need not to be at the same place at the same time when working in a project and are needed to empower industry with a faster and more powerful decision making process [3]. Cyber-physical systems are growing and is a big part of the industry 4.0 evolution [6]. The market is exploding with both the technologies such as apps and wearables [7] and consulting firms that could perform the service of using VR and AR. More and more companies are considering an increase of digitalisation in parts of the company for example an increased use of these technologies. But the question is why the technologies have not been used more in manufacturing before and why it is still not used that much? As with all new

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technologies there are social and technological barriers connected to its implementation to industrial reality [8]. By utilizing learning factories most of these barriers can be overcome through early contact with the new technology. This helps to minimize the possible fears of workers and managers especially in the context of demographic changes in industrialized countries [9]. This paper aims to show some cases using extended technologies in different phases in the production systems and future potential of the technologies.

2. Extended Reality technologies

Extended reality (xR) is a term referring to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables. There are different types of xR technologies i.e. Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR). Figure 1 shows the relation between different xR technologies the transformation from real environment to virtual environment.

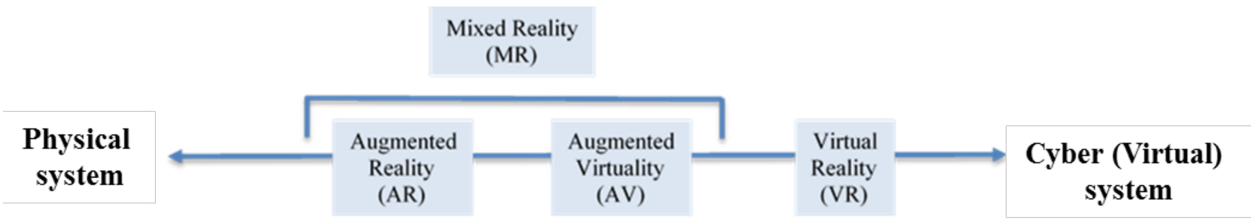

Fig. 1. Relation between xR technologies and environment, adopted from [10]

Mixed Reality can be defined as both the real and virtual are mixed, where the virtual augments the real and the real augments the virtual [11]. *Augmented reality* can be defined as a technology used to "augment" the visual field of the user with information necessary in the performance of the current task [12]. AR exhibits following properties: combines real and augmented objects, runs interactively and in real times, and registers (aligns) real and augmented objects with each other [13]. This transition is facilitated by dynamics of AR that complement human associative information processing and memory [14]. Augmented reality is mostly used for remote guidance and visualisation of instructions used in complex assembly, disruptive tasks or training in an existing environment [15]. Augmented reality could be divided into three different types i.e. Hand-held device (smartphone or tablet), Head-worn (glasses) and spatial (projector/hologram) [16]. *Augmented Virtuality* consist of higher level of virtuality than augmented reality, mostly referred to as mixed reality, and is used for visualisation of new products and visualisation of for example picking procedures. In augmented virtuality, a higher proportion of elements are synthetic in nature [10]
In *Virtual reality*, users are completely immersed in a virtual world and cannot see the real world around them. Virtual reality allows a user to step through the computer screen into a three-dimensional (3D) world. The user can look at, move around, and interact with these worlds as if they were real [17]. The technology can be used in different phases in manufacturing. Virtual Reality is most common for product development and marketing [18], it could also be used for training, ergonomics [19] and visualization of digital factories (design phase, could be both green-field and brown-field applications) [20]. In the section below, some examples from industrial case studies will show different environments and technologies for xR in manufacturing.

3. Case studies

Five case studies have been conducted during 2015-2017 with 220 participants from academia and industry. This section will describe the most important findings in the case studies with focus on testing, validating and usage of xR technologies i.e. Augmented Reality, Mixed Reality and Virtual Reality, in manufacturing. The cases were also performed in different phases of the manufacturing i.e. design, learning and operational phase.

3.1. Augmented Reality

Two of the case studies used Augmented Reality (AR) head-worn and hand-held devices. The first case is a complex set-up of a product and the second case is assembling of a gear-box. In total 115 participants tested this technology. The hard- and software tested in the two industrial cases is from XMReality.

In the first case an advanced set-up in a calibration fixture for quality control. The set-up is usually made by experienced operators[21]. 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. The test consisted of fifteen test persons, where five persons assembled the part on the fixture with existing instructions and the remaining ten test persons were instructed through the AR glasses with the help of remote guidance. The expert guide the novice operators by observing the task through the camera in the middle of the glasses and then tell if there is something wrong with the assembling. Figure 2 shows a novice and an expert using the remote guidance for lego assembling. Every person did the set-up four times. Parameters such as quality and time was considered as KPIs. How often the test person looks at the instructions or removed the glasses are additional parameters that were controlled and measured. The set-up time is 30 percent shorter using AR for novice operators compared to the existing instructions.

In the second case, eight participants assembled four gearboxes each at an assembly station. The gearboxes were assembled with guidance from a remote instructor through augmented reality. Four different types of instructions were compered i.e. Remote guidance with AR, movie based instructions, Face-to-face and text. Figure 2 shows the set-up of the remote guidence and the operator assembling the gear-box. The picture to the left is the novice operator that is being guided by the expert on the right picture. The expert can point and show components using the camera. This creates an augmented reality in the novice operators glasses that helps assembling the gear-box.

Fig. 2. Using Remote guidance from XMReality

The different support tools result in different assembly times for the first assembly, ranging from 109 seconds with face-to-face instructor to 415 seconds with remote guidance with augmented reality. For remote guidance with augmented reality the average assembly times were around 25 seconds longer for each assembly. Hence, the quality were best, 100 percent with AR compered to face-to-face were the quality had an average of 89 percent. The same assembling of the gear-box was performed at a technical fair where 92 participants assembled the gear-box remotely with help from an instructor, 87 of these were very pleased with the technology and thought it was easy to use.

Summary of Augmented Reality

AR can give instant feedback, which makes it almost impossible to assemble wrong and result in high quality. This advocates the AR technology for more advanced and longer tasks within manufacturing, such as complex set-ups, operations with many tasks/long cycle time and advanced maintenance. There are a lot of AR-wearables on the market now, table 1 summaries the most common wearables including XMReality with some of the most common parameters that usually are compared [16]. Since there are so many different glasses it is important to see were the most common area of use is.

Table 1 Most common wearables within Augmented Reality

Parameter/Glasses	XMReality	Epson bt-200	Meta 2	Vuzix M100	Atheer AiR	Penny C-wear
Price [USD, 2017]	7900	700	949	1080	3950	3000
Weight [g]	400	88	420	44	135	66
Transparent lenses	Video see-through	Optical see-through	Optical see-through	Video see-through	Optical see-through	Optical see-through
Resolution	800x600	960x540	2560x1440	240x400	1024x768	873x500
FoV (Field of View)	40 degrees binocular	23 degrees binocular	90 degrees binocular	15 degrees monocular	50 degrees binocular	42 degrees binocular
OS	Windows/ Android	Android	Windows	Android/iOS	Android	Windows/ Android
Battery life	2.5 h	1.5 h	Powered by computer	1 h	n/a	3 h
Most common Area of Use	Remote Guidance	Logistics	Marketing and sales	Assembly	Assembly/ maintenance	Assembly

The participants in the case studies see most potential within logistics (picking and kitting operations) and guidance for complex assembly/set-ups. Training was also an important area. Some of the part (sub) areas within guidance were; support experienced operator, give indications of time and quality, short descriptions on costumised components (assembling), check-lists and indicators instead of long text-based instructions for maintenance. The most important KPIs was quality, time, flexibility, and cost. Unique Selling Points (USP) were to get young people into industry by working with common technologies that exists outside industry.

3.2. Augmented Virtuality (Mixed Reality)

The case study was using a head-worn immersive hardware from Homido and an Android AR-app displayed in a smartphone mounted within the immersive hardware [22]. In total 35 participants performed the assembling. The case is to assemble cardboard glasses, illustrated in figure 3

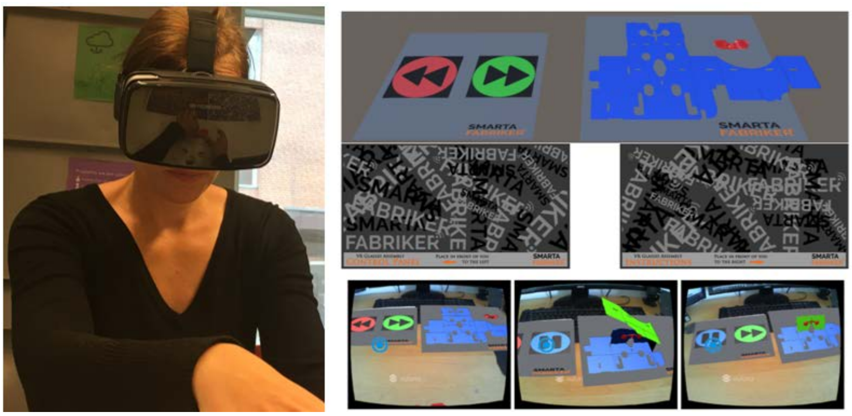

Fig. 3. Assembling cardboard-glasses with MR-applications (https://youtu.be/WTdKCr1l-I0)

The operator starts by playing a comfortable length of the animation and assemble accordingly. A blue tracker displays the virtual objects at a fixed position, meaning that the trackers can be moved or rotated and still display the virtual objects. When any of the buttons are activated the button's image will turn blue and the arrow becomes a pause symbol, to visually indicate that the button has been pressed. When any of the buttons are pressed the green components will move according to the assembly sequence. This is to visually guide the operator to focus on the current parts that are next to be assembled. Results shows that some of the participants felt uncomfortable using the MR-instruction. They did not appreciate the immersive wearable, creating a poor field of view and losing depth-vision which sometimes caused dizziness afterwards. It also took longer time to assemble the cardboard glasses using this technology then video instructions or picture-based instructions. This could depend on inexperience using immersive technology and AR-application for assembling. The instruction is sensitive to lights, sometimes the trackers is lost and the virtual objects disappears from the operator's view. It was observed that some participants had a hard time to properly understand the functions and how to use the glasses during the assembly. It would be interesting to extend the tutorial to several minutes to see if it would affect the MR instructions performance. Using another type of MR-technology e.g. Microsoft Hololens would enable better integration of available guidelines and could also offer solutions to the immersive related problems because the see-through.

Summary of Augmented Virtuality (Mixed Reality)

This is the least developed xR technology and does not have too many products on the market. Microsoft Hololens and sometimes the META 2 glasses are classed as MR glasses. In 2018 there are a lot of new mixed reality glasses launched to the market were Microsoft is part of five new releases (Samsung, Acer, HP, Dell and Lenovo). It is important to ´know the aim of using the glasses. Now this technology is mostly used for assembly tasks, marketing and sales, visualisation of instructions and visualisation of 3D environments layered in reality.

3.3. Virtual Reality

Two case studies were testing VR-technology using the head-worn immersive glasses from HTC view. A virtual assembly training tool was developed for the same gearbox used for augmented reality. Eleven participants were performing the assembly operation [23]. Unity was chosen as the development platform for the training tool. The individual CAD models of each LEGO bricks that consist the gearbox were imported into Unity. HTC vive was selected as the head mounted display and a handheld controller for the test subjects to visualize and interact in the training environment, seen in figure 4.

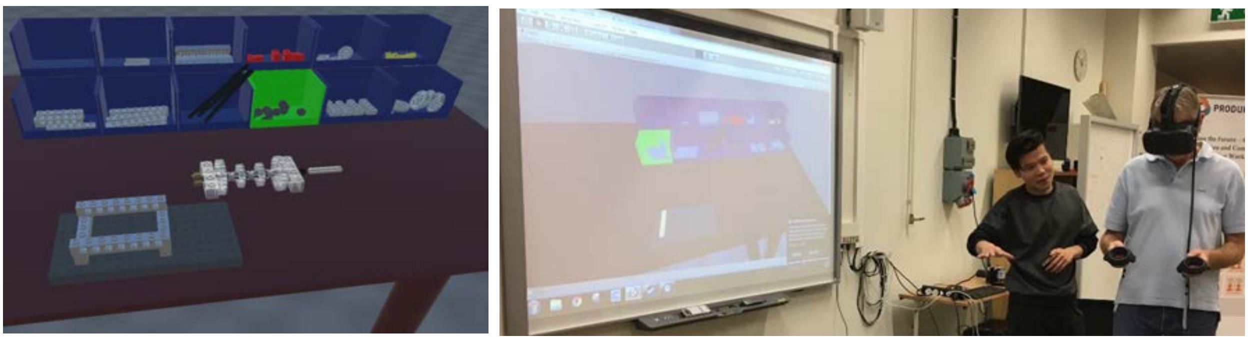

Fig. 4. Assembling Lego gearbox in Virtual Reality

The training session was developed based on the pick-to-light principle [24] with a given assembly sequence. During the training session, the box with the right bricks to pick up for assembly was highlighted and visual aid is provided for the precise assembly position of that selected brick.

After test subjects have correctly placed the brick to the assembly position, the system will move on to the next one until the completion of the gearbox. The assembled two in Virtual Reality and then three in real life. Results show that assembly quality is better than the average of other scenarios (Text, movie, face-to-face and AR). It is also interesting to note that assembly quality dipped to 81.8% in the transition from virtual to real environment, but climbed up again to 100% right after the first physical assembly. It is clear that the first assembly in all five scenarios took the longest time, then quickly shorten in the later attempts. Movie-based instructions took the longest time of 414.9s for the first assembly, but gradually improved to 83.5s in the last attempt, which is as fast as other groups. The IVR group spent 130.7s and 140.9s in their first virtual and real assembly respectively. The switch from virtual to reality was not smooth as the completion time increased from 87.2s to 140.9s in the transition. In the final assembly round, IVR achieved the shortest average completion time (80s) of all.

This second case demonstrate how brownfield design [25] of a factory segment could be discussed with help of Virtual Reality. There were 40 participants testing this technology. Brownfield design is often used for product design, but could also be used to describe redesign of shop-floor segment. Brownfield design could be defined as reusing of available assets, and that there are limitations in designing and solutions because of the existing structures [26]. This is often the case when a segment is about to be redesigned and it can be hard to see the possibilities and limitations solely based on 3D-CAD models. The aim was therefore to test virtual reality to create the shop-floor segment so that the operator could walk around in the suggested design and discuss pros and cons with the design. From the companies point of view the purpose was also to test the technology in their own factory to gain an understanding of how they can benefit from it. Dynamic torques have also been incorporated into the model, such that the monitors to the packages are rotatable. The torque was loaded in order to test if there is enough room for changing a roll of material placed behind the monitor.

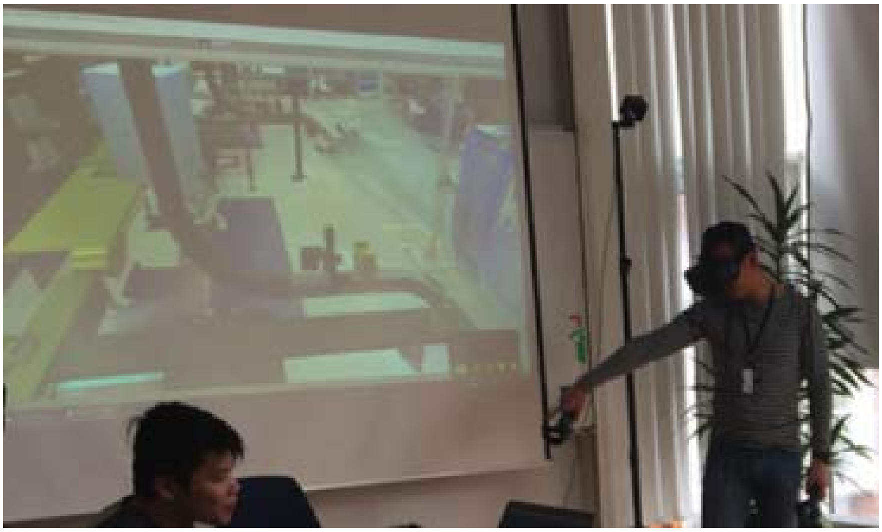

Fig. 6. Work shop with the new design suggestion using HTC vive and Unity environment

A survey with four questions was asked; 1) easy-to-use the technology 2) See a clear benefit with the technology 3) useful for my job 4) recommend the technology to others. The strongest and significant correlation is between easy to use and recommend (0,939), which means that the attendees thought that is was easy to use and under-stand the tools, but also that they would recommend the tools to others.

Summary of Virtual Reality

This is the most developed technology since it has been developed and used in gaming for a long time. The most common areas of use for VR is product development, re assembling and training.

4. Discussion and conclusion

There is no doubt that the xR technologies are here to stay, the question is where and when to use them? In order to answer these questions practical experience and knowledge needs to be built up within the organisations. One way to do this is to test technologies in a learning factory (Testbed).The five cases show that there is a need to distinguish between different phases in manufacturing depending on cycle-time, cost-savings, time efficiency and easy-to-use. Figure 7 shows a summary of the experiences that was built up during the experiments and case studies within this paper.

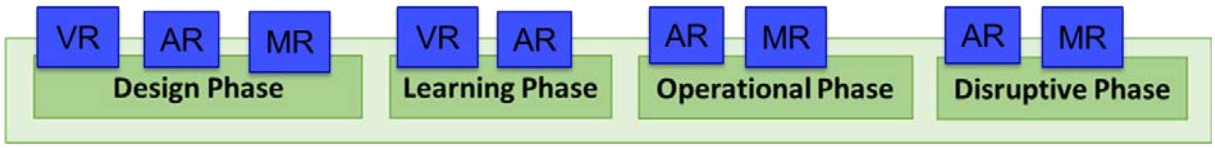

Fig. 6 Different phases within assembly system and when to use what xR technology

VR is very useful in the design phase, for example for factory layout planning of a new shop floor section, on the contrary it was not very useful in the operational phase since it is an immersive technology, the immersive technology also but demands on computer graphics and processor power in order not to lack and make the operators sea-sick. The participants had a hard time when going from VR to real assembly situation so it might be good to have a learning station IRL to.

MR is the most flexible technology and could be used in almost every phase, here is the hard-ware that is the biggest limitation. This technology has the most potential for the future since it could be used in most phases. Since it is note immersive it has also a better user experience than VR technology.

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

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