Augmented Reality and its Upcoming Trends in Engineering

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Abstract

Currently, virtual reality and therefore also its related research fields experience a revival. This is mostly due to new hardware developments like the HTC Vive, Microsoft HoloLens and many others. Hence, also augmented reality is now getting a chance to develop further and make interesting breakthroughs. The goal of this paper is, firstly, to give a short overview of state of the art augmented reality technology in general. Then, its new chances and possibilities in the field of engineering are presented, with respect to the classic product lifecycle. In each phase of this lifecycle, possible ways to integrate augmented reality within are covered.

Keywords: augmented reality, engineering

1 Introduction

In 1968, Ivan Sutherland [1968] built a device he called "The Ultimate Display". It was attached on the user's head and fixed on the ceiling. With different sensors, it was able to track the observer's point of view. Two cathode ray tubes were used to display wireframe graphics, and with half-silvered mirrors, the user was able to simultaneously see the computer generated images and his environment. This system he built was the first virtual reality head-mounted display. Since then, virtual and augmented reality have steadily improved. Today, sophisticated hardware like the HTC Vive [HTC 2018] and the Microsoft HoloLens [Microsoft 2018] exist. Big companies are integrating functionality for this devices in their software, e.g. Autodesk's design software "Fusion 360" [Autodesk 2018]. With a recent Windows 10 update, Microsoft released the "Mixed Reality-Viewer".

For the engineering domain, augmented reality is especially interesting. This is because on the one hand, it supports the collaboration of virtual product designs and the environment, and on the other hand, is leading to new ways of implementing computer aided engineering. This article will give an overview of augmented reality in general and will later describe where augmented reality can be integrated in the workflow of an engineer based on the product lifecycle stages design, validate, build and maintain.

1.1 Existing Reports and Papers

A good introduction is "A Survey of Augmented Reality" from Ronald Azuma [1997]. It is one of the standard papers in AR (7178 citations according to Google Scholar, last accessed on 03.11.2017). It was released in 1997 and is now about 20 years old. A quite modern (2015) and very detailed survey was written by Mark Billinghurst et al. [2015]. This article complements Azuma's insights with recent applications.

These reports will serve as a source for presenting the basics of augmented reality. After that, we will get more into detail about engineering. The focus in the literature research were modern papers, e.g. from Palmarini et al. [2018], which investigates new methods in product maintenance. Nevertheless, the reader also gets a general introduction at every stage of the product lifecycle in order to understand its needs for augmented reality support.

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1.2 Definition and Related Terms

First of all, we start to differentiate augmented reality (AR) from its related terms virtual reality (VR) and mixed reality (MR) to be then able to define it in a more formal way. There are a lot of models defining the relationship between reality and virtuality, but the most basic definition is Milgram's Mixed Reality continuum [Milgram and Kishino 1994].

This model names the transition stages between a real and a virtual environment and sets them into relation. As can be seen in Figure 1, AR lies between the real world and the virtuality, but it is nearer to the reality. As an example, an AR system may be able to augment virtual furniture in a real room. Augmented Virtuality (AV) in contrast lies nearer to the virtual world. A virtual room where a real chair is integrated would be an AV system. MR includes both, AR and AV. It does not restrict itself to systems, where the real-world is superimposed by virtual content, but also can be used to describe virtual environments containing selective real components.

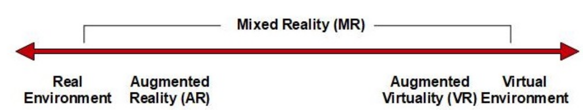

Figure 1: Milgram's mixed reality continuum.

So now that the relation of AR and the real world is defined, the first of three points in Azuma's definition of which properties AR systems must have, can be understood and verified: [Azuma 1997, p. 1]

1. Mix the real and virtual world,
2. be interactive in real time,
3. and combine the content with the real world in 3D.

So according to point one, a game is not AR if it is not registered to the real environment. For example Pokemon Go [The Pokemon Company 2018] fulfils this point. E.g. the film "Avatar", in whose scenes the actors and the virtual creatures seamlessly coexist together, violates point two, because the media is not interactive. Regarding point three, with a digital video camera, 2D information like battery usage is blended on the screen in real time, but these elements are not spatially registered with the camera image. How this content can be integrated into the real world will be covered in an overview in the next chapter.

2 Technology Overview

In this section, important aspects which are needed in order to build AR systems are introduced. In fact, the core technologies needed to comply with our previously defined points are tracking, display and interaction technologies [Zhou et al. 2008] [Li et al. 2017, p. 17].

2.1 Display

Azuma's definition in Section 1.2 does not specify with which technology the system is implemented. In early times of AR, a lot of special devices, like head-mounted displays, were built to provide AR to researchers. In the last years, the most handheld devices have gotten enough computing power and sensors to bring AR to a broader audience [Zhou et al. 2008, p. 197-198].

The first set of displays are **head-mounted see-through displays**. See-through displays are usually divided into the two classes optical see-through (OST) and video see-through (VST) [Zhou et al. 2008, p. 197-198]. In OST, the user can directly see the reality through the display, which overlays this view with virtual elements. This is also the advantage of this kind of displays. Because the real objects can be directly seen, of course they appear most natural. In VST, the real scene is captured by a camera and then shown on a display. In this case, the resulting camera stream can be used for further processing like special effects. Also, a finished image is more consistent with the original one. Head-mounted displays are still widely used today and at present, a lot of new devices like the Microsoft Hololens (OST) are beeing developed. Mainmone et al. [2017] are currently working on new holographic near-eye displays at Microsoft Research. In this distinction, they can be classified as OST.

The second type of display is the **handheld display**. As already stated in the beginning of this section, with the rise of the handheld devices, AR was now suddenly very easily available for a lot of potential costumers. They are at least as mobile as head-mounted displays, quite affordable (although most of the users have a mobile phone) and are currently more socially accepted. But not only the hardware is easy to obtain - a large number of AR libraries are being developed or were ported to handheld devices, the most prominent example beeing the tracking library ARToolKit [artoolkit.org 2018]. Others examples are Vuforia [PTC 2018] and ARKit [Apple 2018]. According to the differentiation we made in the head-mounted display section, handheld device AR can be categorized as VST.

AR systems with **projection-based displays** are using, as can be read from the name, projectors. The main point for using projection is the fact that multiple users can see the AR scene and they do not have to wear head-mounted displays. Of course, this technique is mostly used in a stationary way, and a tough problem can be inconsistent illumination due to overlapping projections. Overall, projection-based displays are not used very often in engineering contexts, mostly because of this properties. An example of an exception is the work of Ashish Doshi et al. [2017]. They used a projection-based system to mark surface points for spot-welding in order to increase the accuracy.

2.2 Tracking

In order to superimpose the virtual content, the system must be able to track the user's position and field of view (FOV) to determine which objects are displayed and how they should be blended into the view. This is important to give the user the illusion that the virtual objects really coexist with the reality. Billinghurst et al. also see tracking as the most important technology for AR applications because of this very fact. In the table where they introduce AR and VR technology requirements (see Table 1), the tracking need for AR is labelled as "high accuracy needed" [Billinghurst et al. 2015, p. 80].

	Virtual Reality	**Augmented Reality**
Scene Generation	requires realistic images	minimal rendering is okay
Display Device	fully immersive, wide FOV	non-immersive, small FOV
Tracking and Sensing	low accuracy is okay	high accuracy needed

Table 1: Comparison of AR and VR in terms of needed technology.

Over the years, a lot of tracking methods were developed. In the trend investigation of Feng Zhou et al. from 2008, they distinguish between sensor-based, vision-based and hybrid tracking techniques, and therefore, we will use this differentiation here too [Zhou et al. 2008, p. 195-196].

2.2.1 Sensor-Based Tracking

The first type of tracking uses sensor data to connect the virtual to the real world. Magnetic sensors, for example, are small and have a high update rate, in exchange they are prone to inference by magnetic fields or objects. The output of these sensors are open-loop. This means that there is no feedback with which errors could be corrected automatically. In contrast to sensor-based tracking, vision-based tracking is closed-loop and therefore has such an error feedback [Zhou et al. 2008, p. 195].

Other types of sensors collect inertial, mechanical or even acoustic data. As seen by the magnetic example, all sensors have strengths and weaknesses and therefore, scientists also try to combine different kind of sensors to compensate their disadvantages. Today, most handhelds already contain a lot of different sensors, like for inertia or the Global Position System (GPS). These are often combined. (see Section 2.2.3.)

2.2.2 Vision-Based Tracking

The other class of tracking uses cameras in order to calculate the camera position and FOV with the help of digital image processing methods. The picture taking does not always have to work via the visible spectrum. Especially in early AR days, tracking was also done by infrared [Billinghurst et al. 2015, p. 105-106].

In the beginning, artificial symbols with embedded patterns were used to keep track of the relation between real world and virtual object. A good example is (as already mentioned) ARToolKit [artoolkit.org 2018], which uses this kind of patterns for tracking. Nowadays, tracking systems also work with more complex approaches like natural feature tracking, model based and 3D structure detection [Billinghurst et al. 2015, p. 106-112].

Natural feature tracking detects features like corners, edges and even textures from an image. A prominent example of such an algorithm is the Scale Invariant Feature Transform (SIFT). This feature detector is able to retrieve robust features which are independent of the scale and rotation of the image. Basically, SIFT first builds a multi-scale representation of the gradients of the image using the "Laplace of Gaussian" (LoG) pyramid. Then, it extracts the local minima and maxima as interest points, where unsuitable features are discarded. For each feature, orientation (calculated with the local gradients) and scale level are assigned to provide the named invariances. In the end, every feature gets a so called "SIFT descriptor", which combines the pixels in the 16x16 region around the interest point to 4x4 areas. For each of this 4x4 areas, the gradient magnitudes are put into a histogram with eight bins, which results in 4x4x8 = 128 values for the SIFT descriptor. However, because of SIFT's computational expense, algorithms like Speeded Up Robust Features (SURF) were developed to do real time feature tracking [Billinghurst et al. 2015, p. 113-119].

The idea behind **model based tracking** is to use CAD models to anchor the two environments together. Originally, these models where made by hand out of primitives like lines and curves. An edge filter was applied over the desired image and the primitives were simply matched to the resulting image. To improve the results, e.g. textures or natural feature tracking can be added. Modern approaches tend to use algorithms that can create a map of the surrounding and locate the camera pose concurrently, like Simultaneous Localization and Mapping (SLAM). Because this algorithm is especially useful for 3D structures, it is described in the next paragraph [Billinghurst et al. 2015, p. 119-120].

3D structure tracking directly analyses the 3D meshes generated by reconstruction systems. For this, a 3D point cloud of the surrounding environment has to be collected. The first method to do this is using special RGB-D cameras [Henry et al. 2012]. The D indicates that this type of camera has an additional depth component. An affordable example of such a camera is the Microsoft Kinect [Microsoft 2018], which is able to take stereo images. With these stereo images and triangulation, the distance from the viewpoint to feature points can be computed. If there is no RGB-D camera available, methods like "structure from motion" can be chosen. Here, the fact that the camera moves is used to estimate the depth component. After the resulting point cloud is available, statistical outliers can be eliminated. Then, an algorithm like SLAM can be applied [Durrant-Whyte and Bailey 2006]. SLAM can be formulated as an estimation problem, because it tries to estimate the viewer's and several so called "landmark's" (points of the environment) positions via an observation model. This can be done for example with the "extended Kalman filter" (EKF-SLAM). Finally, the resulting reconstructed 3D environment can be used to e.g. track 3D models [Billinghurst et al. 2015, p. 120-122].

2.2.3 Hybrid Tracking

As the name suggests, in the hybrid approach, sensor- and vision-based tracking is combined to deliver either even more accurate or application-specific data for selected AR problems. In the paper of Zhou et al. [2008, p. 195-196], outdoor working AR systems are mentioned as an example for needed hybrid tracking. Here, sensor-based tracking like GPS or inertial sensing have to be combined with the vision-based technique, because vision-based tracking alone is insufficient. An example application is the wearable AR kit of Ribo et al. [2002], who build an wearable AR kit for outdoor applications which uses computer vision and inertial and rotation sensors.

2.3 Input and Interaction

AR itself can be seen as a completely new human-computer interaction (HCI) method. It can be described as a way to get users away from traditional graphical user interface toolkit elements like windows and buttons and more into directly manipulating the content, therefore improving the usability [Billinghurst et al. 2015, p. 78-79]. For the interaction overview, the following terms describe different important approaches people already used to implement AR interaction techniques [Billinghurst et al. 2015, p. 165-178], [Zhou et al. 2008, p. 196-197].

Navigation is the interaction principle used in AR information browsers, where additional facts are blended over the real world. The user looks at special scenes and decide with this action which information should be displayed. Therefore, this kind of "view navigation" can be seen as an easy way to navigate through AR spaces. Of course, the drawback that no further direct interaction with objects is possible should be mentioned.

3D user interfaces like spaceballs, 3D-mouses and special joysticks have already been developed when 3D modeling software and 3D computer aided design (CAD) applications needed a more versatile input methods. Because of this, they can also be used for AR. This is mostly due to the fact that on one hand side, the virtual world is implemented in 3D, and on the other hand side because our world is three dimensional as well.

Tangible user interfaces are integrating real objects into the interation. Because the aim of AR is to make a bond between reality and virtuality, it is not unreasonable to do this. These interfaces work really well because physical objects are part of people's everyday life and we already know how to handle them. Therefore, an intuitive understanding of tangible interface may exist in advance or at least will develop very fast. An example application of such an interface is an HTC Vive controller, which is used to place and move virtual furniture in a room. Tangible AR can also be combined with other interaction methods like voice and gesture commands, which results in multimodal AR interfaces.

With **natural user interfaces**, the user specifies the commands via several gestures like moving a hand, a finger or the head. With image processing methods it is possible to track those body movement of a person in real time using just a camera. The advantages are the fact that in case of vision-based body tracking, no sensors mounted on the body are needed, and gestures are easy to learn and apply. However, also biometric approaches exist where, for example, a small wristband measures the muscle nerve activity and can compute from this information which hand gesture was made.

Hybrid user interfaces use different interaction methods, which are complementary. An example would be to combine a gesture based approach with additional voice commands. This mix of interfaces could also be called a multimodal interface, as stated earlier. Of course, such combinations have the advantage that multiple user groups' needs can be targeted individually. For this, some experiments exist where a hybrid approach was used. Often, the scientists not only mix the input technique, but also other technology like different displays [Billinghurst et al. 2015, p. 174-176].

Finally, **collaborative user interfaces** are used in collaborative AR, which is a special term to describe AR applications for multiple users. This kind of AR enables shared workspaces for people who don't even have to be in the same room. Billinghurst and Kato [2002, p. 69] also developed an AR remote conference interface with HMDs. This interface improved, according to their case study, the communication of the users, because they were able to fully concentrate on the social interactions in the shared space. The usage of wearable devices also makes it easy to deploy and run these applications [Billinghurst et al. 2015, p. 196-206]. However, these kinds of setups are not formally evaluated very much, and as a result, there aren't a lot of usability studies in a scientific context available. Nevertheless, this aspect of interaction is very important when AR is integrated in an engineering process, because collaborative work is today essential in every product stage.

3 AR in the Engineering Process

After this short examination of the core technologies needed for AR we will look at the use cases in the engineering process, which can be solved or supported by AR. Credle et al. [2008, p. 15]. show a simple four-phase overview of the life cycle of a product in the book "SOA Approach to Enterprise Integration for Product Lifecycle Management" (see Figure 2), which we will use to explore the applications of AR in every phase.

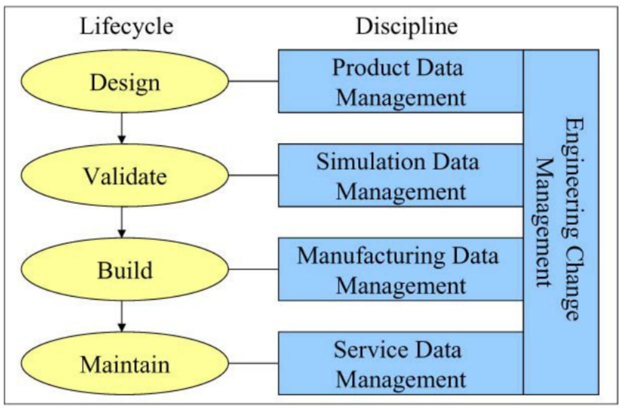

Figure 2: A model for the product lifecycle and its corresponding data management disciples [Credle et al. 2008, p. 15].

So the phases are design, validate, build, maintain. At every stage, there exists a type of computer aided process to increase the productivity.

1. Design - CAD is used to specify, design and visualize the product.
2. Validate - Computer-aided engineering (CAE) is used to analyse and simulate the conditions in which the product should operate.
3. Build - Computer-aided manufacturing (CAM) is used to generate instructions for computer numerical control (CNC) machines to manufacture the designed parts.
4. Maintain - Computer-aided maintenance helps with learning and performing maintenance work.

Therefore, at every stage, AR can be integrated to provide further advantages like in visualization and interaction [Wang et al. 2016, p. 1].

3.1 Design using AR

CAD was a big step in the history of product design. At the beginning, not only every sketch of a product, but also every engineering drawing had to be done by hand. With the help of computers, it is now possible to design the product in 3D and then derive and export the 2D drawings from the model. After this is done, the engineer just has to add manufacturing-specific information to the drawing, like dimensions and surface roughness. However, more and more of these are today added at the 3D model stage. This saves both time and money because it connects the development stages and does a lot of the drawing work. Another positive side effect is the fact that the product can firstly be visualized much more easily and in an earlier phase than back then, and secondly it can be used for rapid prototyping.

Engineering and scientific visualization was already done very early with VR, but a quite modern case study in the context of prototype visualization (with VR) was done by Marks et al. in 2014; The first study was the visualization of a neural network, which is a quite abstract concept. The second study was a VR space containing a yacht, on whose deck the viewer could look at a virtual sea and sky. The yacht designer described the VR experience as getting a new perspective of the product, which would without VR only be possible with a real prototype [Marks et al. 2014]. In the case of the yacht, its virtual environment was fully augmented, but in this field the future chances for AR are to visualize virtual prototypes together with its real environment where they will later be performing, e.g. a virtual industrial robot in a real production line.

An impressive example of the visualization of mechanical parts using AR was done by Figueiredo et al. [2014], also in 2014. The aim was to teach first year mechanical engineering students how 2D drawings of 3D shapes are connected. Figueiredo et al. used two models, one of them visible in Figure 3. They then used the free smart phone application Augment (see Figure 4) and also a hologram technique to visualize them in AR. Their future goal is to do a classroom study of the visualizations [Figueiredo et al. 2014].

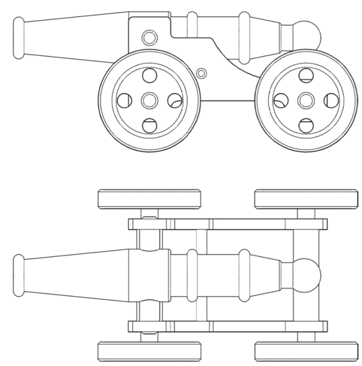

Figure 3: The drawings of a cannon [Figueiredo et al. 2014].

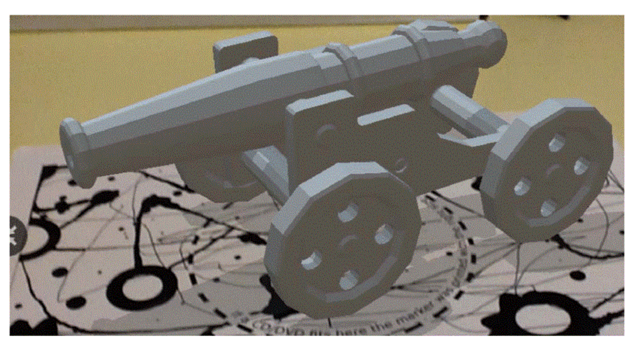

Figure 4: The AR visualization of the cannon [Figueiredo et al. 2014].

So as we can see, there are a lot of possibilities to visualize parts and assemblies with AR, but there are also attempts where the design process is directly done in the AR, for example in the work of Huang et al [2015]. They designed and implemented an AR CAD system with touchable 3D input and stereoscopic display. They describe that the main advantage of this system is the fact that certain barriers of traditional CAD applications are removed, because mostly these systems contain a lot of functionality based on converting 2D input with keyboard and mouse into the 3D model space. With an AR system which uses 3D input, not only the interface is a lot easier and more intuitive to use (for example 3D splines can be directly edited in 3D), but also the visual feedback helps a lot more because the user can directly inspect and understand the currently edited shape. For display, they use a spatial optical see-through approach. It has to be said that the visual feedback is happening in real time. The system also supports physically existing parts in the same scene with the virtual objects together while still being able to render both with correct occlusion effects. The stereoscopic effect achieved with the monitor and active shutter glasses ensures spatial perception of the scene.

The operations implemented in this system range from classic object movement and rotation to adding either predefined primitive shapes like boxes or drawing freeform shapes by specifying 3D points with a pen, which can also be done directly on the surface of physical objects. Also, more sophisticated actions like combining objects with Boolean operations are possible. Figure 5 shows as an example the interface where the user can specify the desired model-view manipulation. E.g. the blue highlighted first button from the top reads R and is meant to chose rotation as an action. In the Figure, there is also the teeth model from one of the test cases visible, which will now be described [Huang et al. 2015].

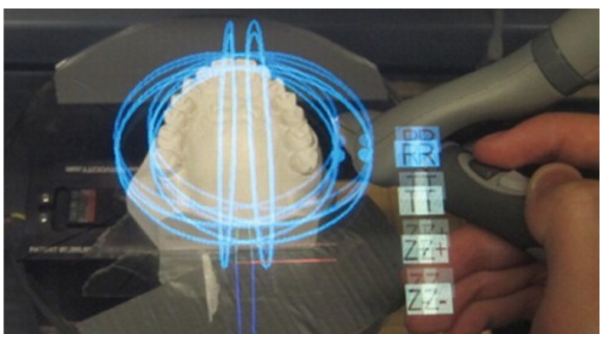

Figure 5: A possible lightweight interface for an AR CAD application [Huang et al. 2015].

In the end, Huang et al. executed some test cases with the system, one of them was to design a dental brace wire for the given teeth model in Figure 5. Five CAD experts were asked to do this task and everyone of them agreed that the novel AR system led to a better user experience than conventional systems. These test cases not only showed the great usability but also the big potential for further work.

3.2 Analysis and Simulation using AR

Most of the physical problems appearing in engineering can be described using mathematical models. With numerical analysis, these problems can be well approximated, and because of recent advances in computation power, it doesn't take a lot of time to get satisfactory results. Further, numerical solutions can also be visualized to enable engineers a deeper and more intuitive understanding of the problem. Analysis and simulation software development was started as the first computer systems were developed. The most used numerical method to simulate e.g. structural integrity, heat transfer and fluid flow is the finite element analysis (FEA), which basically first divides the model mesh into sufficient many and small triangles (therefore, finite elements). Then, the physical model is either transformed to be solved by a linear equation solver or be solved approximately (for example with Newton's method) in order to get for example stresses like tension or shear in every point. The advantage of this method is not only its simplicity and scalability but also the fact that it is easy to visualize (see Figure 6). Common simulation applications nowadays use the classical windows, icons, menus, pointers (WIMP) approach, which controls are pretty complex and hard to learn, so AR may provide a better interface for such sophisticated software.

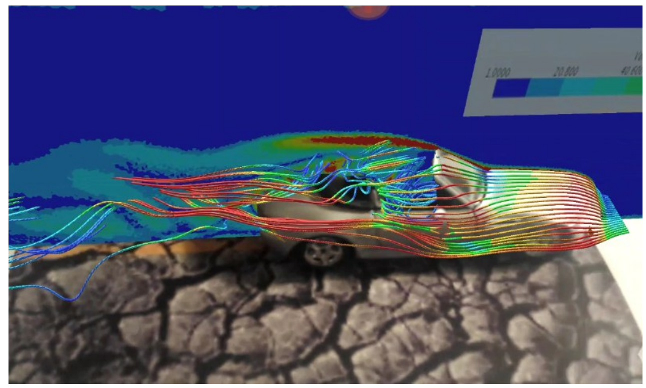

Figure 6: Visualization of a computational fluid dynamics (CFD) simulation of a BMW Z3 (https://fetchcfd.com/view-project/370).

Li et al. [2017] provided a state-of-the-art review of current research trends of AR in engineering analysis and simulation. They collected several recent papers and divided them into the sections "Biomedical engineering and surgery", "Civil and urban engineering", "Mechanical engineering and Manufacturing" and "Electromagnetism". They then studied their characteristics and limitations and summarized common features in the Table 2. So as we can see there, most of the observed systems were designed within one too specific scope, therefore lacking multiple platforms, other application areas and dynamic content. It also shows that AR in simulation and analysis is mostly used as a visualization tool and not as a interaction method. For the future, Li et al. propose the integration of AR into already evaluated systems, improve mobile AR solutions and to implement more sensor networks and ubiquitous computing.

Features	**Limitations**
Robust tracking performance is required for high precision engineering operations	Designed for one specific scenario with pre-defined model hardcoded.
Efficient visualization tools are implemented for near real-time display	Mainly developed on one platform only. The lack of multi-platform support limited the usage of the system.
Accurate registration of computer-generated volumetric data and numerical simulation result on real scene	Most of the system lacks effective and intuitive interaction method. The system was only used for visualizing the results

Table 2: Frequently observed limitations and features of analysis and simulation applications [Li et al. 2017, p. 11].

3.3 Manufacturing using AR

Today, manufacturing processes are getting very complicated due to the fact that some products are getting more complex, the production lines have to scale even more and some products need to be mass customizable. An example for the opportunity of AR in this field would be to get integrated within these manufacturing processes in order to ensure that everything is working fine before the first real production run is being executed. (Although this would also require simulation, the methodology needed for this was already covered in Section 3.2.) This is possible because of AR's property to mix virtual objects with the real assembly lines. Further, production nodes can be connected and share e.g. the virtual product models. In 2008 where Ong at al. [2008] did their survey on AR manufacturing, there were already a lot of applications identified, ranging from layout planning to welding and machine tools.

Now, current research trends in this field are introduced. These important processes of manufacturing need to be planned, especially for big and complex assembly lines. For this, there are process planners who inspect the CAD model of a part or assembly to decide how to manufacture/assemble it. Wang et al. [2016] did a special survey on assembly research which shows well how AR can be integrated in a manufacturing process. Actually, AR is one of the most recent promising technologies here, because firstly, it can reduce costs by not requiring the whole environment to be modelled as stated before, and secondly, because the users can work in a more direct way with the models and e.g. are able to better derive the needed assembly conditions from them.

In **assembly guidance**, AR provides a way to inform the user of the next assembly step and ideally recognizes and reports possible manual errors. For this, the system has to keep track on the current status, which is called "context-awareness". The problem here is to make the system really adaptive and flexible, because most of the recent research systems only support identifying a special assembly state. An example for a part distinction mechanism was implemented for circuit boards with SIFT [Radkowski and Oliver 2013].

In **assembly training**, new employees are taught assemble tasks. Here, it has been shown that AR is very effective. In several studies, users have shown to be significantly faster with using AR to support the assembly work. But also here, the error feedback is minimal because the systems have a difficult time identifying the assembly state. Another approach was to monitor the activity by supervisors, which are able to inform the users if they make a mistake.

In **assembly process simulation and planning**, the planners have to identify the order of bringing the parts and sub-assemblies together, and for this, the dependencies between them need to be determined. The current improvement work with AR is done by making the CAD models more tangibly to the planners. Figure 7 shows how a virtual assembly case study can look like.

A very recent work of Ni et al. investigated another subtopic in the big field of manufacturing in combination with AR. In this paper, an AR system to program a welding robot was presented. The prototype was a virtual robot which was able to control using haptic feedback from a smaller tangible model. In the end, Ni et al. did a user study which showed how user-friendly this approach is. However, the accuracy is limited due to the tracking sensors, so in the future, this aspect needs to be improved [Ni et al. 2017].

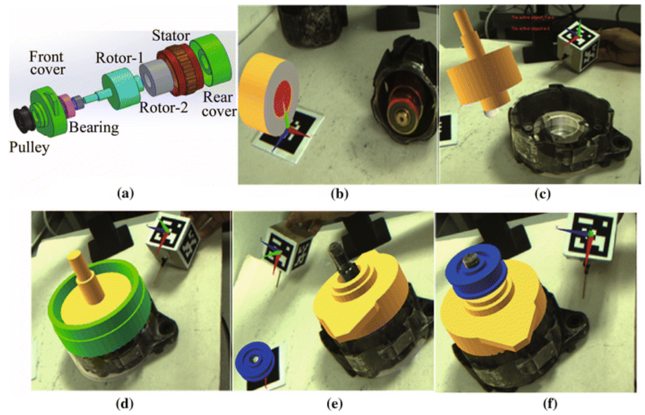

Figure 7: An example AR assembly process of an alternator [Wang et al. 2016, p. 14].

3.4 Maintenance using AR

The goal of maintenance is to bring back the functionality of a product in its lifecycle. First efforts of using AR to improve maintenance and repair work were started about 50 years ago. As the users studies in Section 3.3 showed, AR definitely has the potential to teach and support technical tasks, so in this section, the current state of these applications is going to be investigated.

Acoording to Palmarini et al. [2018], who did a systematic literature overview, aviation, industrial plant and mechanical maintenance are the two upper thirds of the most promising fields. Aviation maintenance is complex and therefore, the industry needs to find a way how to reduce human error and with this improve security. For the two other fields, maintenance cost is an important criteria. Up to 40% of the total lifecycle costs from automotive vehicles can be maintenance costs. In case of facilities, this can even be up to 85% of the total costs. The last third of the application field collection from Palmarini et al. consists of consumer technology, nuclear industry and remote applications (where an expert assists a maintainer in his work remotely).

The different maintenance tasks are diagnosis (identifying the issues of the products), dis/assembly, repair and training. Like described in Section 3.3 with assembly, repair and diagnosis are supported by AR information and interaction. The aim of AR in this field is often to replace a long training phase of the maintainers with an AR system which gives the worker direct maintenance instructions. Because training is wanted to be abolished, maintenance training with AR is the smallest research field.

For current AR maintenance systems for the operators, head mounted displays are the best and probably only hardware option because the system has to be wearable and of course the maintainer needs both hands free in order to work. Therefore, AR on mobile devices like tablets cannot be used for maintenance jobs. In case of instruction visualization, the most systems use 2D or 3D animation. This especially helps untrained operators to fulfil the tasks. The visualization can also take place statically, a few systems just use text. Additionally, audio guidance can complement the instructions. These are either given by the instructor in case of remote maintenance or played back by the AR system. Authoring (creating content for the AR system) is mainly done manually. This is known as the content problem, because manual creation of content needs programming, modelling and animation skills and is very expensive. This problem has a lot in common with the problems described about assembly guidance in Section 3.3, where the lack of context-awareness was mentioned. Currently, there are approaches which try to add virtual annotations in order to make authoring easier.

Figure 8 shows two different levels of instruction help from Webel et al. [2013]. Also, it shows an example view of how a maintain worker would see and interact with the maintenance system. Webel et al. implemented this system and provided two instruction modes: a strong guidance mode where the system shows the worker each necessary step and all of them are visualized in detail, and a soft guidance mode where an experienced worker is able to obtain high-level information about the whole maintenance process.

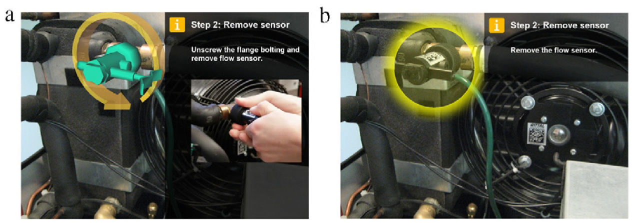

Figure 8: The two instruction modes. Figure 8a shows the "strong guidance", Figure 8b shows the "soft guidance" [Webel et al. 2013].

AR maintenance in combination with cloud manufacturing (offering product design and manufacturing as a service) might also be able to trigger the development of new business models. Large manufacturing companies like BMW and Bosch are interested in this field. Mourtzis et al. [2017] developed an example of a service and cloud based AR platform which enables manufacturers to offer remote maintenance. Here, the technician is able to generate a malfunction report via the cloud service, then obtain maintain instructions and in the end evaluate his work. Here, AR instructions can be used from the remote expert in order to provide better explanation of the tasks. Because of the cloud infrastructure, CAD models of the maintained machine may be available to even automate the dis/assembly instruction generation. In the end, the framework was evaluated in a case study provided by a robotics company where normally, special technicians have to replace battery packs of an industrial robot. With the presented system, the maintenance expert could be replaced with the automatically generated AR instructions, which reduces the cost from € 1370,00 to € 150,00.

Adding everything from this section up, it is clear that maintenance is a really important and cost-critical stage in the product cycle. For the future, Palmarini et al. predict an improvement of existing hardware, tracking and registration algorithms and better user interaction. They describe hardware improvements like more energy-efficient and FOV-richer head-mounted displays as well as new hardware inventions like AR contact lenses in the "not so far future". From the algorithms perspective, they identified like the other groups in this report that tracking is a bottleneck for real-world application of AR systems. Regarding the interaction, new tools and methods for authoring and content management are needed together with more adaptive systems. Also, there is research going on to automate content creation.

4 Conclusion

In conclusion, there is a lot of hope that AR will improve our existing systems, making them more intuitive to use, more productive and easier to share. If we listen to all of our current research results, it seems that scientists may be right with this assumption, and step by step, AR changes the picture we have about computing. It is not any longer just a toy but may be a core technology of a lot of future engineering systems, whether they are made for design, verification, production or maintenance. And there are much more application fields, like archaeology, architecture and teaching.

After collecting the results of all these materials, it seems that especially mobile AR will further grow in the future. Tracking algorithms are currently improved to not be dependent on markers any more, there is a lot of optical see-through display research going on and scientists are developing new interaction methods for these systems. Overall, AR research and applications are growing day by day, alongside with VR.

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