Chapter 14
Major Technology 8: Augmented Reality—AR

Executive Summary

This chapter deals with the following topics:

- Basics and advanced techniques of Augmented Reality
- Providing insight into how engineers benefit from using Augmented Reality (AR) technologies
- Describing functioning, benefits, and limitations of AR technologies in practice.

Quick Reader Orientation and Motivation

The intention of this chapter is:

- to give an overview of AR technology in Virtual Product Creation as driver and enablers for Digital Transformation in engineering
- to present AR technology as part of Virtual Product Creation from a practitioner's point of view to analyze the need and usefulness for day-to-day industrial work practice
- to give instructions on how to use AR technology
- to explain models, frameworks, and mathematical representations that help to grasp the internal working modes of AR technology.

In contrast to Virtual Reality (VR) applications, the Augmented Reality (AR) approach enriches *real world objects* with computer generated perceptual information *by means of an overlay*. As being part of the wearable computing research segment and industry, AR stands for a multimodal augmentation; it is often related to the visual sense to see both worlds simultaneously—an intelligently projected virtual image blended with the real three-dimensional environment. The benefit lies in the augmentation of the user's visual perception of his physical surroundings with additional and meaningful context-sensitive information. With advanced technologies such as computer vision, virtual objects become executable for visual consumption and are the base for extended user interaction within working scenarios.

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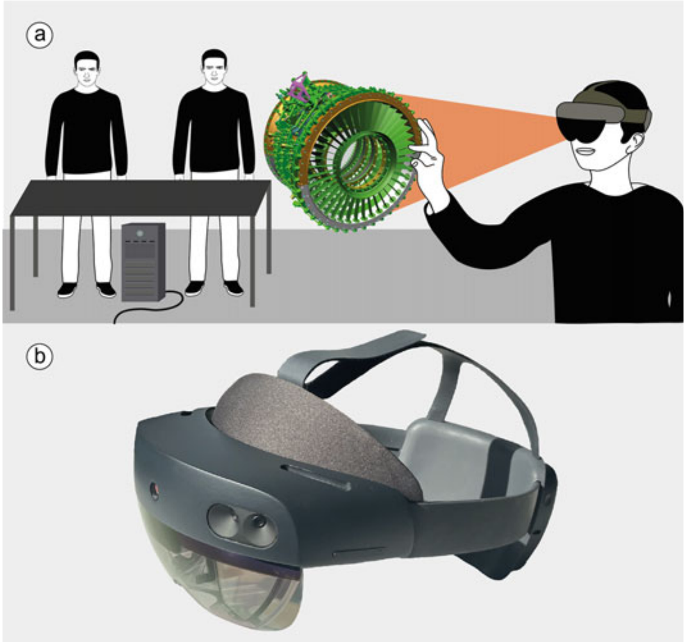


Fig. 14.1 **a** The AR principle of viewing digital content (example digital aero engine model) in the context of a real environment (e.g. office, test facility etc.); **b** Microsoft HoloLens 2 as an example for a Head Mounted Display [2]

The beginnings of industrial AR range back to the 1960s with first research prototypes, while the development ramped up steadily between the 1990s until today. Since then, the technology has evolved from being the subject of experimental research projects to being able to deliver effective and scalable applications that assist engineers during their daily work. Today, big tech companies like Microsoft, Google and Apple have identified AR as a key technology, investing heavily into it and already providing robust hardware and software solutions (see Fig. 14.1) [1]. Modern AR head mounted displays like the Microsoft HoloLens 2 shown in Fig. 14.1 (compare [2]) allow for up to 1–2 h of continuous interactive working meanwhile.

In 2018, AR was stated as one of the ten most strategic technology trends [3] with the potential to influence the technical development long-lasting. A recent study conducted by Deutsche Bank predicts that until 2020, the global market for AR will increase from 500 million Euro to 7.5 billion Euro [4]. Improved hardware and tracking algorithms make AR increasingly attractive [5]. Similar assessments of the technological and application related positioning of AR solutions, e.g. as part of advanced virtual assistants, are yearly assessed by the Gartner Research Group.[1]

[1] https://www.gartner.com/en.

14.1 Engineering Understanding of AR

AR solutions provide powerful technology elements in the context of extended Virtual Product Creation scenarios. Engineers and IT experts integrate AR solutions into numerous industrial processes to achieve state-of-the-art digital connectivity and intelligent virtual support.

Primarily, AR technology is used in planning or execution of assembly, operating and maintenance activities as depicted in Fig. 14.2a. In general, AR can support tasks such as overlaying digital information sets onto real physical objects, assisting humans in understanding and executing specific tasks according to in-situ needs or prescriptive workflow seqeunces and to provide explanations as part of interactive sessions:

- Interactive visualization of interfaces to support engineers, workers and costumers during prototype reviews or planning activities
- Support of context-aware activities and product user assistance as well as training,
- Object localization in the factory or field,
- Visualization of product and process-relevant virtual geometries and information (e.g. geometric differences between a real component and another version of it via virtual overlay).

In addition to industrial AR applications, the technology can add value in several further areas like sales (e.g. customer product presentation and configuration), healthcare (e.g. surgery training and support) and the consumer market (e.g. games, services such as navigation or tourism, head-up displays). Other fields of AR usage exist within education and training as well as in guiding people within tourism and as part of cultural exhibitions.

14.2 Why Does an Engineer Use AR?

Within the overall range of AR use pattern, engineers are increasingly leveraging the following capabilities of Augmented Reality within their task portfolio. Please note the most common ones:

- Early detection of design errors by overlaying CAE results on top of real prototypes in order to compare high stress or strain related areas of a component or assembly.
- Descriptive and meaningful documentation of products and technical systems (and machines) in order to provide "on the fly" direct information sets at a physical product area or feature in order to enhance in-situ checks and understanding of operation.
- Simple communication between all planning stakeholders during reviews of physical objects and prototypes.

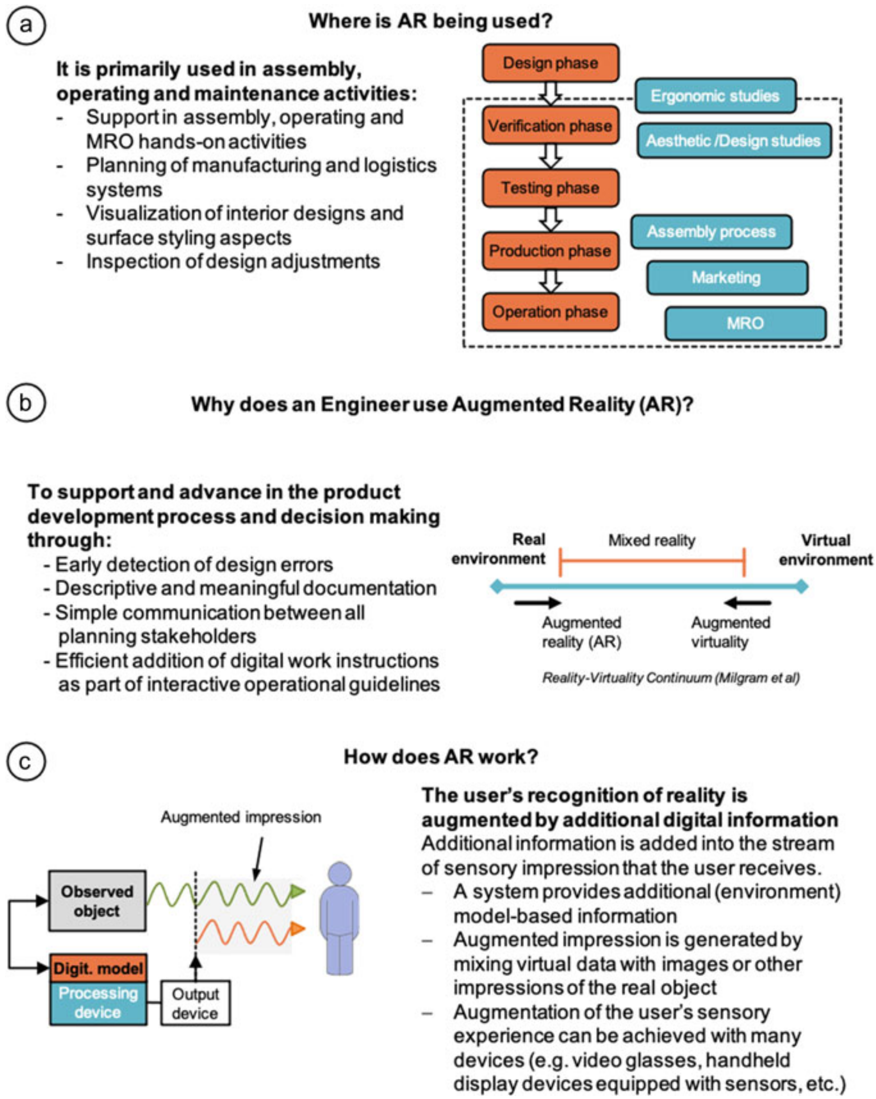


Fig. 14.2 Engineering application of AR (subfigure **b** based on [6])

- Efficient addition to operational guidelines with the help of static and dynamic digital information sets on top or in the nearness of the physical areas of a real asset, gadget, product or component within the MoL (mid of life) lifecycle phase.

Engineers are using Virtual Reality (compare Chap. 13) during the pure digital engineering phase of product creation when no physical objects and components exist. Augmented Reality, on the other hand, is utilized to overlay digital information with physical objects. For a better understanding and differentiation of the related technologies, the continuum between reality and virtuality is depicted in Figure 14.2b. The limit on the left hand represents real world physical elements such as persons or physical objects. The limit on the right hand designates sole virtuality. Here, the virtual environment only models fictional objects, i.e. there exist a completely computer-generated environment that can be arranged in a full immersive set-up. Apart from the controllers' inputs, this "pure virtual" environment is not connected to the physical reality of the context. In between the two opposite sides, the range of mixed-reality expands. Coming from the left, one could think of superimposing lightweight virtual information in Head-Mounted-Displays (HMDs) while seeing the real world that is considered in a context-sensual software application. Continuing to the right, almost complete virtual scenarios that only partially include real components (e.g. real seats, steering wheels or humans). Due to AR's key feature, there is still the chance to see the real surrounding like persons and objects and the scenes are less immersive compared to VR. However, the ability to superimpose digital information is more attractive for many companies and engineers because the real and the digital world can be perceived simultaneously in a specific arrangement. Even though today's virtual and augmented reality applications differ in many ways, experts see a merge of the two technologies in the near future. Indicators of this are development efforts in the sector of video-see-through devices that can switch between the two concepts.

14.2.1 What is AR Doing for an Engineer?

Augmented Reality provides technology support for Engineers in many occasions if the overall AR solution set has been set up for it. The following capabilities of AR are described and illustrated in order to create incentives for engineers to request such AR technologies within their personal engineering solution set.

14.2.1.1 Capabilities of AR in Product Design and Manufacturing

Product design requires many design iterations that consist of both, synthesis and analysis. The latter requires validation tasks of the specific prototypical design stages that AR can support within an intuitive way. A technical example of this is the comparison between virtually investigated simulation results and its real-world counterpart's crash deformation during real tests for validation. This correlation test use case can also be helpful between digital CAD models and complex prototypical components that are built for product integration evaluation. Furthermore, AR enables the chance to reduce prototypical designs to a minimum while replacing certain equipment with virtual holograms. By doing so, time as well as budget efforts are reduced and

Fig. 14.3 **Leftside** superposition of a crashed door with the crash simulation result [7]. **Rightside** augmentation of the virtual engine compartment with the real body-in-white for product validation. (*Source* BMW Group)

concepts are becoming mature in an earlier design stage. The two example use cases are depicted in Fig. 14.3.

In order to ensure manufacturing and assembly feasibility for prototype builds and series production AR offers capabilities known as *Augmented Visual Inspection*: it is, e.g., possible to check and inspect the released product data with the real physical product situation (see Fig. 14.4).

Meanwhile, first applications are under development to improve the interactive positioning and orientation of machines in factory and power plants shop floors. As shown in Fig. 14.5, a CAD-model of a machine is projected into the real world with a HoloLens 2. The user can then place the machine via hand gestures in the room. The translation and rotation will be returned back to the native CAD-program (in this case *Mechatronics Concept Designer, MCD* from Siemens). The AR application provides the engineer a better understanding on how the machines will be placed in

Fig. 14.4 AR based visual inspection of the physical member floor side with its digital product data based on the TWYN system of Visometry GmbH. (*Source* Porsche Leipzig GmbH)

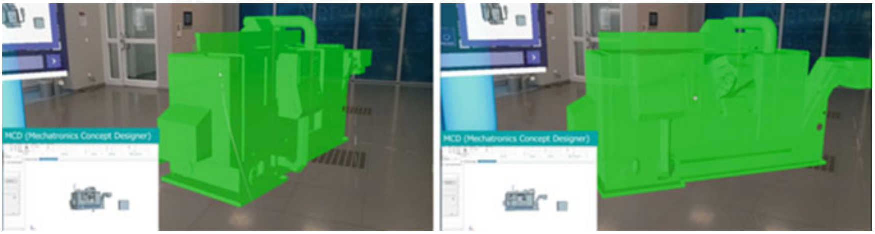


Fig. 14.5 AR application to position an electric drive on a factory shop floor. (*Source* TU Berlin, chair of Industrial Information Technology)

the real context. This will be advantageous for factory and power plant floor design of the future.

Figure 14.6 shows a similar AR application realized on the shop floor of the production site in Leipzig (Germany) of the vehicle manufacturer Porsche.

Such AR solution enables robust digital factory integration planning and layout sign-off between digital planners and station designer with the operational factory floor experts.

Figure 14.7 shows a new type of interactive AR prototype by Fraunhofer IPK to be used in conference room based digital reviews.

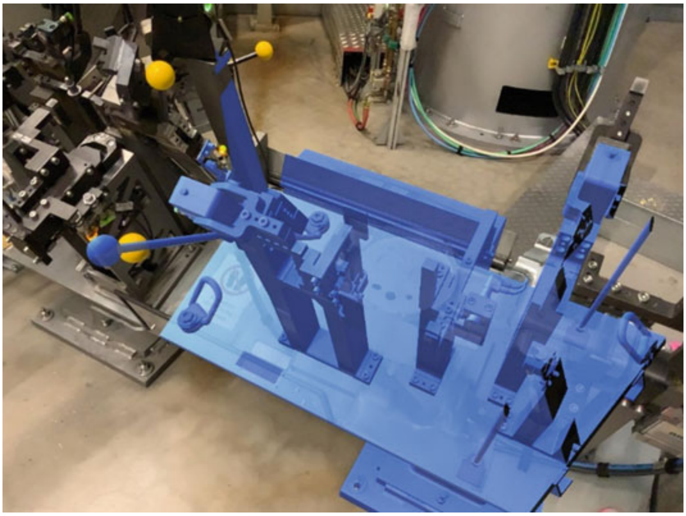


Fig. 14.6 AR based factory shop floor layout integration of a fixture resource based on the SuPAR system of CDM-Tech GmbH. (*Source* Porsche Leipzig GmbH)

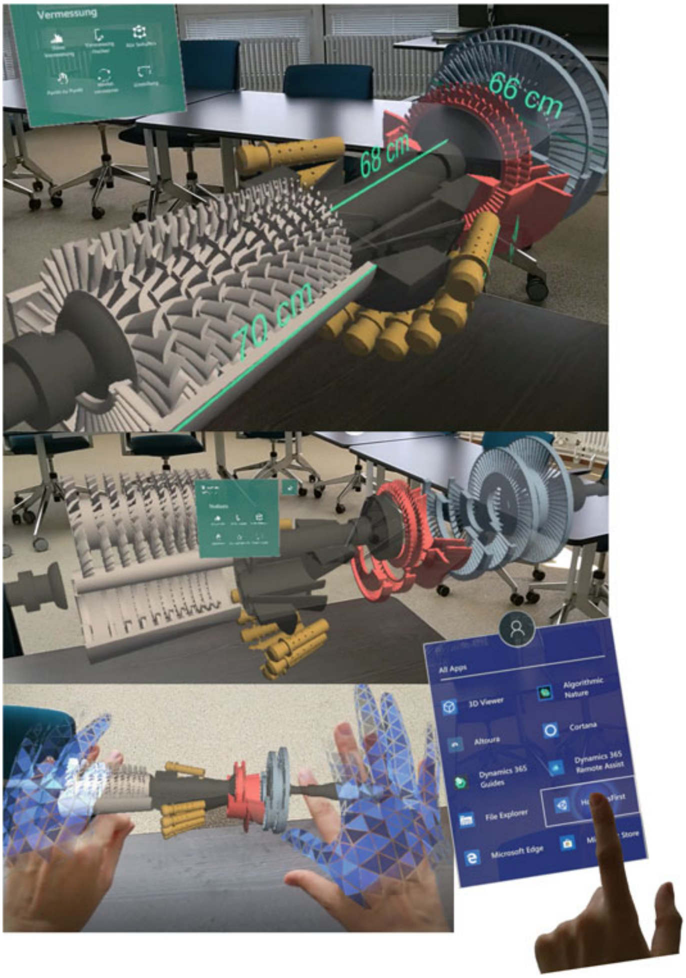


Fig. 14.7 Interactive AR prototype as part of a digital conference room review (example of an aero engine, courtesy by Rolls-Royce)

14.2.1.2 Capabilities of AR for Interactive CAE of Physical Objects

With increasing capabilities of handheld computers—such as tablets and smart phones or of see-through glasses with edge computing devices (or coupled to handheld computers via Bluetooth or Near Field Communication (NFC)—it will be possible to allow interactive AR based CAE analysis directly on the objects in the field, i.e. within the operation environment. As shown in an applied research solution of the University of Singapore by Wenkai [8], it is possible to provide an *AR front end* to the physical environment of a civil engineering object such as a bridge in order to interactively apply different load and boundary conditions to a predefined *back end CAE model.*

With the help of control sequences via the internet it is possible to modify key parameters of the CAE model in the back end and to invoke an instant CAE run for such problem (see Fig. 14.8). The advantage is that non-CAE expert users are enabled to use an appropriate CAE visualization environment directly at the location of the real object in the field. This helps to apply an on-the-fly CAE calculation and visualization of possible alternative solutions of the bridge pillar or trust construction as well as on modified load assumptions directly at an existing bridge that needs to be overhauled or re-engineered.

14.2.1.3 Capabilities of AR in Maintenance and Service

Typically, maintenance tasks are associated with high cost and a greater risk of errors because service technicians do not work in common workflows. To create efficient AR systems and applications, the cooperation between the Bosch Common Augmented Reality Platform and REFLEKT ONE provides several solutions. As an example, AR is used to support the complex repair of passenger vehicles. In this example, a tablet-based AR app supports the technician by highlighting the necessary work steps. Additionally, the application includes an instruction video and a list of required tools and components [9].

Another research-project using and testing AR is the multi-disciplinary joint project ALUBAR [10]. The process of turbine maintenance is supported with a head-mounted display. The project aims to support older workers in their daily activities and to ease the new or re-entry into the employment. The user is provided with relevant information to perform the maintenance, while the findings (e.g. damages) are documented automatically upon a simple command. Due to the interaction with the AR system by voice commands, the user has free hands to work safely and it is not necessary anymore to carry protocols and paper-based information material inside the narrow turbine. As a special feature, the developed AR system is adaptive and responds depending on the user's physiological state. If a certain stress threshold has been exceeded, the system automatically adapts the augmented information. By doing so, expensive errors can be avoided and work accidents are prevented.

14.2.1.4 Capabilities of AR in Commissioning

An example of how AR can support workflows is the use of data glasses applications in industrial logistics during picking processes on shop floors. To reduce error rates and to increase more effective workflows, the user gets relevant information about component parts, e.g. its location in the warehouse and the required part ID. Supported by a hands-free AR system depicted in Fig. 14.9, the user can make use of relevant information in situ via AR-based visual aids. Additionally, data glasses provide visual feedback that informs about the task correctness. A hand-mounted

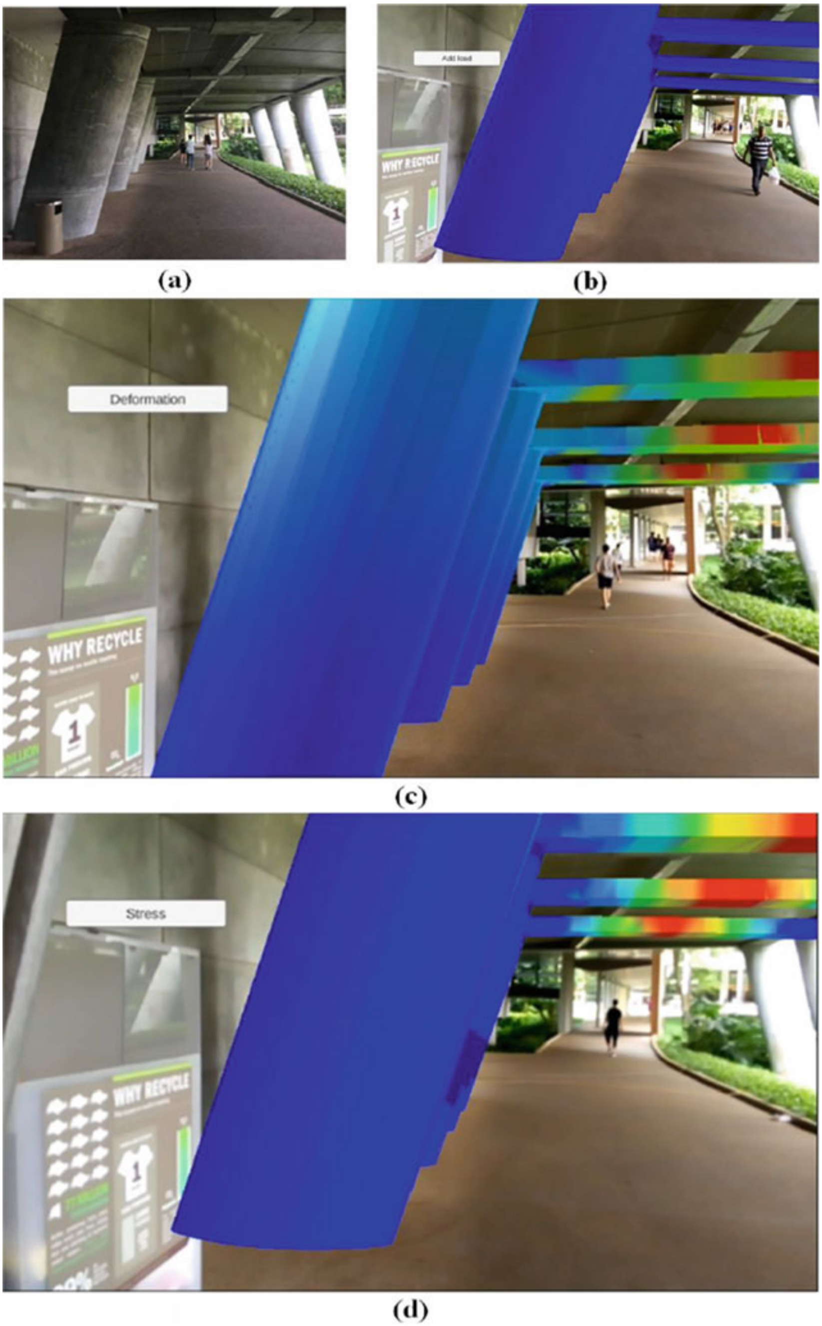


Fig. 14.8 Parameter update in a mobile AR-FEA system (compare [8]). **a** the set-up consists of one natural feature image tracker and target outdoor structure; **b** initial state of the FEA result; **c** stress distribution after loading is added; **d** switch to deformation results display

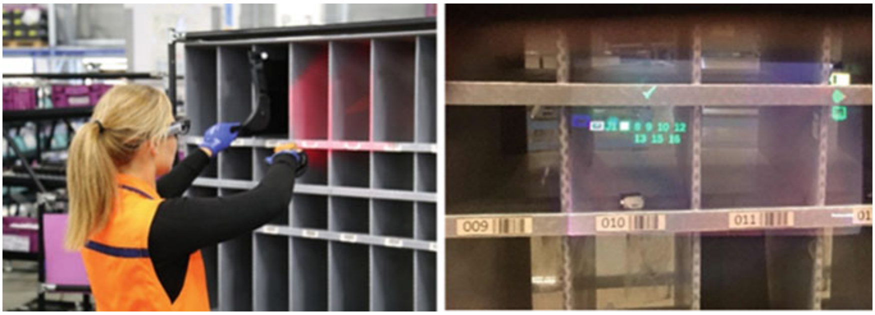


Fig. 14.9 Picking and commissioning process on shop floor in automotive industry. **Left** Photograph of the commissioning task from a third-person-perspective, **Right** Augmented view through data glasses. (*Source* BMW Group)

camera scans automatically the bar code of the component the user reaches for. If the worker takes the correct one, a green coloring appears; if it is wrong, a red visual feedback shows up on the display. User research studies with comparable motivations succeeded and led to high user acceptance and the desired result of a more efficient workflow [11].

Figure 14.10 A shows the virtual commissioning and inspection of an electric drive with the help of an AR based application (developed by TU Berlin, chair of Industrial Information Technology). This AR solution adds 3D-models with attached simulation-data (drive shaft in combination of temperature distribution and bearings in combination with rest-useful-lifetime-estimation) as well as the position, name and index value of the sensors that are used for the inspection.

Through better visualization, this method eases the workflow of the inspection and has an entertaining side effect since it can also be used and followed out from home or the engineering office.

In the real-word, such an electric drive is of very large scale (up to several meters per dimension), so it needs to be inspected from different views. For this demonstrator two mobile phones perform AR-functions from different angles, which need to be synchronized across a network, showing e.g. rotation speed, temperature, sensor positions (compare Fig. 14.10b).

Over another network link, the views of the AR-devices are digitally streamed to a web browser, so the inspection can be conducted from another location. If the electrical drive is not ready for inspection yet, the inspection-workflow can be shown on an AR-model of the machine, so the customer and contractor can be prepared for the real inspection and check if negotiated inspection steps will be performed.

According to [12], other fields of research include Gamification approaches. An example for such capability would be a gamified application for picking processes as part of pre-commissioning tasks in industry.

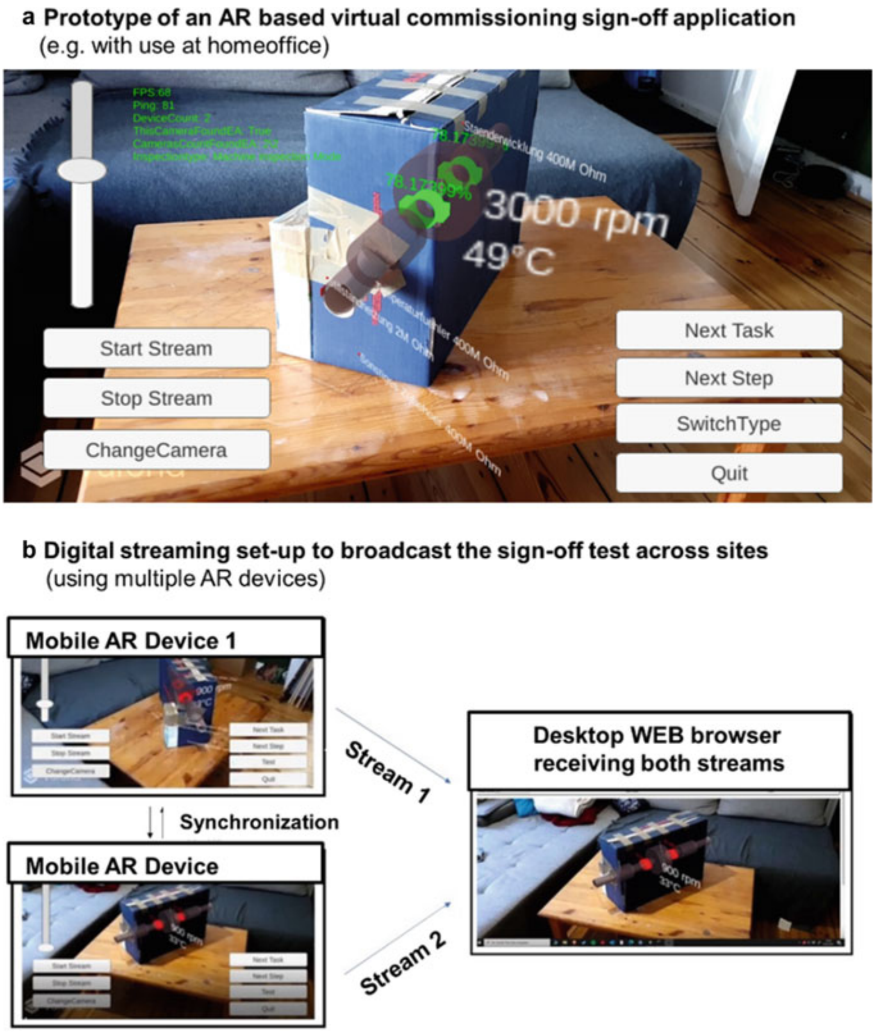


Fig. 14.10 AR application to support far-distance virtual commissioning and inspection

14.2.1.5 Capabilities of AR in Training

The possibility to add instructions to the real environment makes AR attractive for maintenance and training [13]. Based upon the composed sensor data acquisition, AR can be an assistance providing the user appropriate instructions, geometrical paths, work steps or further information. For instance, in a training scenario, an amateur can get information on every single working step (e.g. about tool use, navigational data) to practice a task and prevent mistakes due to the lack of expertise. The handling of particularly complex systems (e.g. aircrafts, industrial plants, etc.)

requires knowledge and expertise that can be supported by AR devices, thus reduces possible damage to expensive systems, and prevents work accidents.

14.2.1.6 Capabilities of AR in Generic Quality Assurance

Quality assurance either prevents or indicates missing, misplaced or defective components. To provide an example, "Werklicht Pro" by Extend3D is a project that develops spatial AR. Digital information about a construction unit (e.g. construction plans) are projected directly on a work piece. Furthermore, projected CAD data and work instructions can support employees in manufacturing and assembly. For enhanced error detection, spatial AR can reveal slight deviations by super positioning of the target state. Thus, quality can be improved and a communication basis about quality development is created. During internal or external product or process audits, AR can support the persons in charge with highlighted positions so that they can be aware of where to lay specific focus on.

14.2.1.7 Capabilities of AR in Remote Collaboration

Due to highly distributed facilities and international plants in automotive manufacturing, remote collaboration plays an important role. For example, when it comes to error detection and remotely supported maintenance of vehicles or manufacturing systems, experts do not need to waste time on expensive business trips, but rather share the captured video stream of an AR device with the colleagues on-site. Annotations can be made in the augmented field of view or voice instructions can be transferred by the sound system.

14.3 How Does AR Work?

As depicted in Fig. 14.2c, AR technology enriches the naturally sensed visual impressions by the human with virtual information based on either a wearable or statically mounted output device. In order to finally render the digital information on a display at a realistic position or at the right time, a computer needs to sense the reality for localization or interaction purposes. This enables the system to react to the users' environment, activities or work steps. The quality and quantity of sensor inputs depends on the use case and the application goal. Today, AR devices are shaped in many different ways depending on the specific use case. More detailed information on the technical side is provided in the following sections.

Figure 14.11 depicts a simplified systems data handling process to show the main functionality and the concept architecture.

In reality, the simplified loop of the system shown above is realized in different sub systems with separate processes run in parallel. Consequently, there is a chance

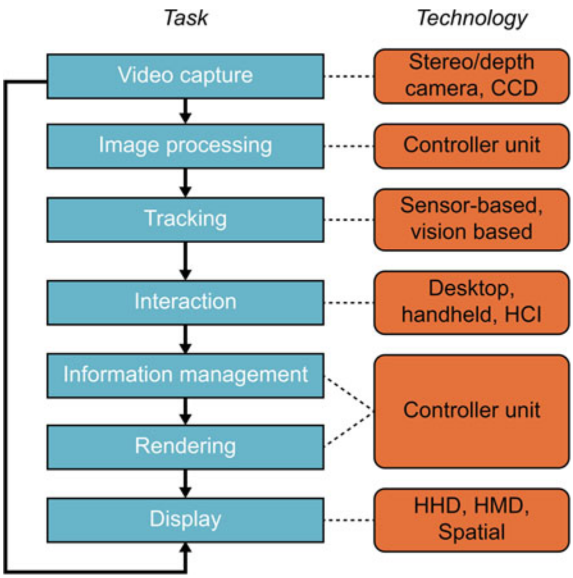


Fig. 14.11 Simplified AR pipeline according to [1]

that tracking rate and frame rate diverge, which can lead to noticeable instability of a ‘static’ virtual object like a virtual chair on the real floor while moving the camera (humans head).

If the tracking rate drops below the frame rate (typically minimum requirement of 60 Hz) or high tracking latencies occur, the object seems to wander during the cameras movement, which decreases immersion [13].

14.4 AR Technologies

AR hardware technologies can be distinguished in mobile and static applications (partially based on [1]). Figure 14.12a explains the three categories of visualization techniques that are used for the mobile and static applications. Mobile applications are supported by the first two categories:

Head mounted/head-up displays:

- *Smart Glasses*, also considered as data glasses or personal imaging system, are used like common glasses and add digital information, e.g. from the internet. Compared to HMDs, Smart Glasses are smaller and less powerful, typically without virtual depth perception.
- Examples: Google Glass Enterprise Edition, Vuzix Blade Smart Glasses, Bose Frames.

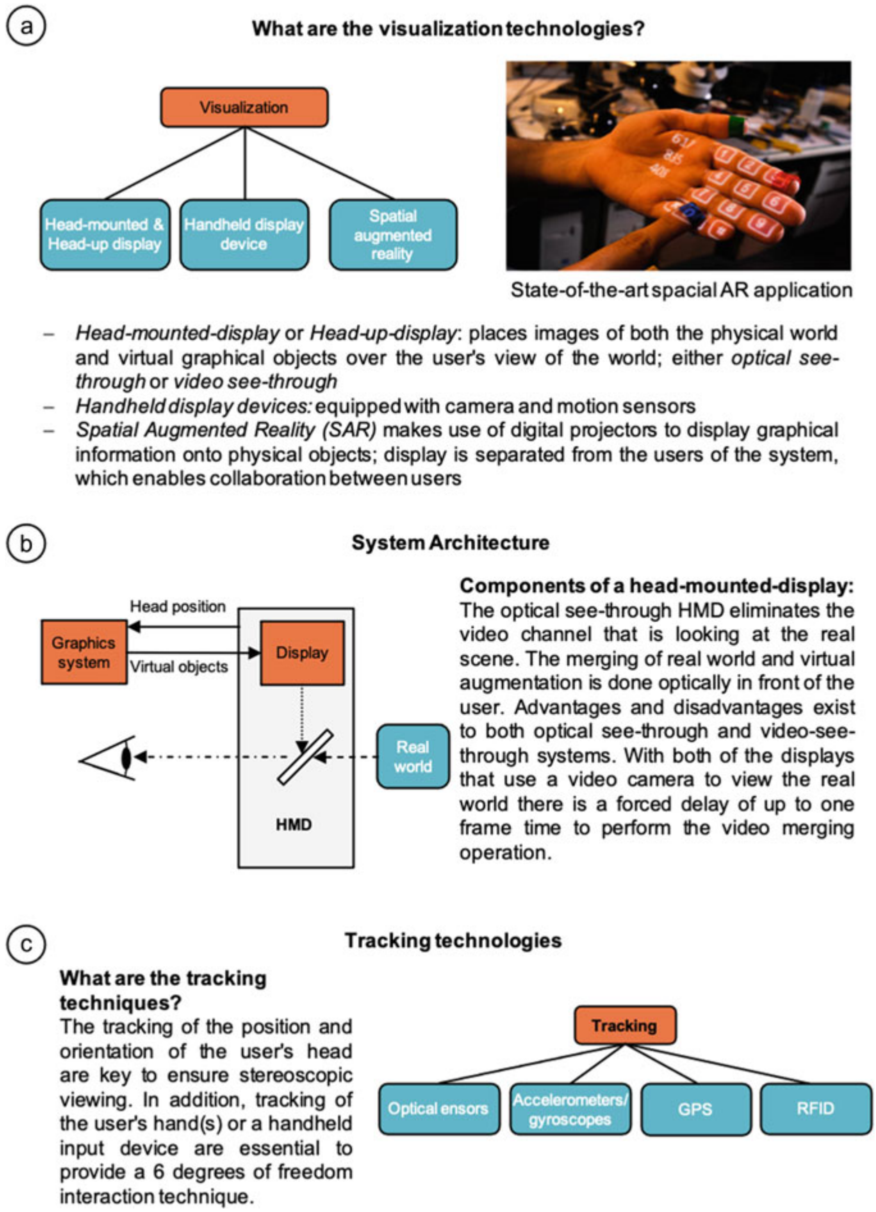


Fig. 14.12 Basis IT technology of AR

- *Advanced HMDs* designed as video see-through or optical see through, see Fig. 14.1.
- Examples: Microsoft HoloLens, Magic Leap (or VR/AR hybrids) and.

Handheld display devices such as:

- *Smartphones, Tablets* (hand held devices) used with AR apps.

Static applications use **spatial augmented reality (spatial AR)** solutions with the help of:

- *Projection based displays*, which consist of an optical projection on real objects. Example: Extend3D Werklicht.

Today's tasks in manufacturing and service require mobile hands-free devices, which is the reason for the recent development effort in the segment of smart glasses and HMDs. The requirement to have the devices as small and lightweight as possible limits the amount of the embedded systems computational power to some extent.

To overcome the problem of computationally expensive renderings combined with small hardware, applications can benefit of streaming the data from another device to the HMD. A drawback of this infrastructure technology are high requirements to the available bandwidth of the wireless connections. Ongoing research is conducted on the use of contact lenses. The desired retinal projection is achieved by directly projecting the virtual object into the eye with the help of a small wearable device. In addition to the wearable concepts, development efforts are taken also in the field of spatial projection. This is realized with the help of static projectors or displays in a dedicated room, as depicted in Fig. 14.13.

The software side can be distinguished in the following low level (embedded programming) and high-level technologies:

- Dedicated operating systems (memory management, hardware drivers)
- Tracking algorithms
- Rendering approaches

Fig. 14.13 Projection of the cockpit texture onto a rapid prototyped design mock-up apart of the automotive interior design process [13]

- Applications e.g. based upon development kits and game engines as frameworks for logic and visual implementations

14.4.1 Setup of AR HMDs/System Architecture

Today, head-mounted AR devices consist of optical components for the real-time virtual projection and of a central processor unit that runs programs and thus receives, analyzes, reduces and sends data. Network capabilities for inter-device communication often are integrated as well. The display typically is either designed as a 'video see through' or 'optical see through' concept (compare the explanations of AR technologies above).

The transparent display visualizes the augmented virtual information in case of an optical see-through-device. Figure 14.12b shows the components of a head-mounted display (optical see-through). In case of a video-see-through device, the collected camera image is rendered on an opaque display. Sensors as cameras (charge-coupled device, stereo or depth sensing), accelerometers, GPS, solid-state-compass or microphones provide the processor with real-world information. The human–machine-interface can be implemented in different ways: for example, via gesture and voice commands to input and to return visual information via display. The experience of the virtual content is realized with the help of intelligent transformation and projection based on the head movements. Digital content either is added based on internal storage or it is pulled from connected devices, such as a database server, an Enterprise Resource Planning System or the internet. Finally, the physical device then is used by an ergonomic element to hold or mount the device on the forehead.

14.4.2 Tracking

Tracking and environment registration approaches extract the spatial arrangement of objects and thus enable superposition of a virtual representation at the desired real-world location. Besides tracking the users head, applications also often require hand tracking, other object tracking and environment tracking. As shown in Fig. 14.12c, tracking can be based on mechanical, electromechanical, optical, acoustical, and inertial sensors or a combination of the mentioned techniques (sensor fusion towards hybrid systems). Today, typically, optical and inertial sensors are used due to their cost efficiency and scalability [7].

Optical tracking approaches can be distinguished into two different concepts (see Fig. 14.14):

- *Outside-in*: Based on the concept of photogrammetry, statically mounted sensors acquire the positions and orientations of pre-defined sticked markers (active) or marker less features (passive).

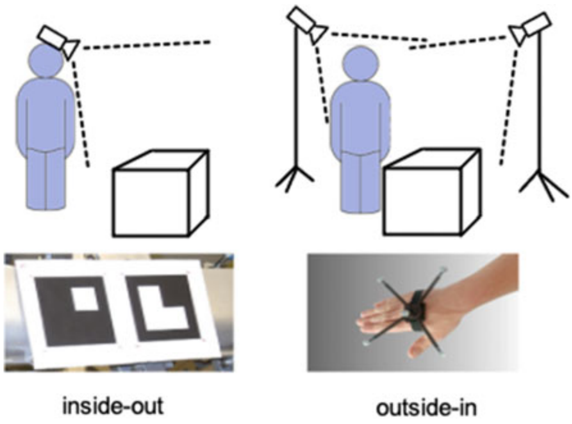


Fig. 14.14 Different tracking concepts with examples of corresponding markers. **Leftside** inside-out-marker [7]. **Rightside** outside-in-marker [14]

- *Inside-out*: A single camera is not fixed statically, but can be moved with the user or object and calculates its position and orientation based on environment features, such as 2D-markers (active) or object features such as specific geometric properties (passive).

The passive feature-based tracking approaches mentioned above are achieved with the help of geometric feature extraction. Beside edge or corner point detection, more abstract features of 2D or 3D objects can also be used for a camera-based identification. Since only a defined percentage of the features are required to successfully track an object, it is faster, more robust (e.g. during the exposure to disturbance such as partial covering) compared to marker-based tracking. The 'Simultaneous Localization and Mapping' (SLAM) approach adapts these feature-based concepts. Without any knowledge of the surrounding, the system incrementally maps the environment and localizes its position and orientation [13]. There exist a substantial global scientific and coding community for markerless AR using algorithms based on line and feature segmentation principles and edge detection methods.

Registration describes the calculation of spatially arranged coordinate systems for each object of interest, so a realistic and congruent perspective can be rendered even when the camera (the user) moves.

It is important to note, that an AR system also requires special "viewing" features and algorithms in order to achieve realistic occlusion in accordance to the rules of line of sight, i.e. it needs the ability to hide virtual objects behind real objects. The challenge stems from the fact that the display used to project the virtual content usually is closer to the eye than the physical environment. A possible solution is to introduce phantom models that overlay the occluded virtual objects (see Fig. 14.15) by using tracking sensors and computer vision algorithms. When these phantom objects are rendered black on AR displays with additive color composition, they will appear transparent to the user [5].

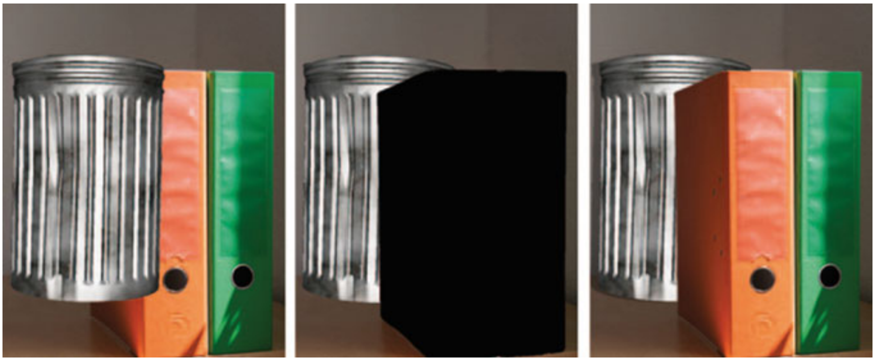


Fig. 14.15 Solving the problem of virtual objects (bin) behind real objects (folders) by introducing phantom objects (center figure) [13]

14.5 Human Interaction

For HMD devices, AR enables tremendous possibilities to realize human–machine interfaces for human input and output.

In order to make use of AR's potential, it is beneficial to rethink old window-based, two-dimensional UI paradigms by introducing 'spatial interfaces', which are much more natural to the human brain. The goals are to reach natural interactions based on previous experiences made in the real world. This makes a challenging learning curve of artificial workflows almost obsolete.

To reach this purpose, user interaction in the context of AR is considered an open field of research [15]. This is, however, similarly applicable to VR-interaction (compare Chap. 13).

Due to the diverging device characteristics of AR HMDs, a high variety of UX implementation concepts, which integrate the sensors and software logic, exist to interpret users' input:

- *Tangible interfaces*: physical devices (e.g. buttons, scroll wheels, virtual pens)
- *Haptic user interfaces*: tactile UI (e.g. touch or vibration feedback)
- *Camera-based interaction*: gesture control, ray-cast pointer of the camera, eye-tracking, object identification, depth camera
- *Audio-based interaction*: voice commands via microphone, environment sound
- *Interaction based on other sensors*: location tracking (e.g. GPS), Infrared sensors, etc.

As an example, virtual buttons can be placed wherever the user wants, e.g. on a virtual object to form an interactive control panel. Hand gestures and voice commands could round off the natural experience by looking at a previously identified real object to directly operate it, open its interaction menu or make it display the operating status. Combining the concepts mentioned above results in hybrid approaches that enable state-of-the-art intelligent multimodal interaction.

14.6 Development for AR Applications

After the 'Make or buy' question was clarified critically with regards to the commitment to individually work on AR software, developers coming from the traditional desktop development may need to leave old paths to engage in the new spatial thinking and interaction.

14.6.1 System Selection for Industrial AR

To successfully select and implement an AR app in an industrial environment, the following application-oriented considerations provide support in analyzing and determining important requirements (partially based on [16]).

Problem/application:

- Performance requirements: e.g. amount of objects/polygons
- Depth information requirements (2D: data glasses, tablet; 3D: HMD)
- Level of real-world consideration (tracking, object detection, etc.).

Environment:

- Infrastructure for data provision and exchange
- Need for mobility (local computation/rendering on external client, network connection)
- Consideration of environment variables (physically robust device, battery runtime, exposure to wear, etc.).

User:

- Desired degree of immersion (display resolution, field of view)
- Time and frequency of personal AR exposure
- Physical characteristics (weight, ergonomics, etc.)
- Acceptability of situational distraction by the virtual content.

Implementation (framework selection):

- Complexity: Static content (low), dynamic 3D-content (intermediate), interactive experience (high) helps to decide on possible software frameworks
- System integration (e.g. data bases)
- Deployment (app, program, internal service via locally installed software or remotely hosted-service via mobile web)
- Scalability
- Reusability.

Software development kits, such as ARKit (IOS), ARcore (Android) or Game Engines are helpful to avoid reinventing the wheel for high level AR application development. Efforts for standardized data formats are made for example with the

'Augmented Reality Markup Language'. This format describes the AR scene, such as its contents locations and appearance for geographic annotations in AR browser applications.

14.6.2 Implementation Design

Once the hardware and development platform is selected, the implementation can be initiated. Implementation of interactive AR applications is a multi-domain composition of three engineering professions as shown in Fig. 14.16a:

- *Systems engineering* (which type and degree of technical system or consumer/game environment need to be constructed?)
- *Software engineering* (how can such system environment be implemented by algorithmes and data?)
- *Usability engineering* (how can the user interaction be most proficient?).

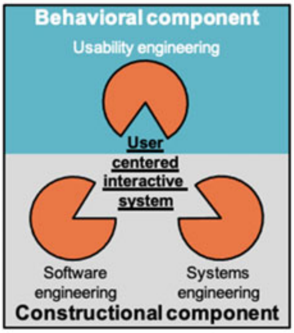
To guarantee an effective and user-friendly user experience, the main points to be considered during software implementation can be clustered in three main categories (based on [17]):

- *Environmental design*:
  To be aware of the users' surrounding they are engaged with, such as space and situational context like public or private environment. This needs to be considered for example for the amount and size of virtual information, or device options as display brightness.
- *Interaction design*:
  To choose the right way of interaction regarding input options, feedback, which is at least partially also related to the context mentioned in the first bullet point, and other factors such as device capabilities or ergonomics.
- *Visual and audio design*:
  This cluster covers content, size and type of visual information, such as 3D objects or 2D information that was projected in the spatial real world. Shadow and Lightning play an important role in terms of immersion. In addition, it may be enhancing usability to implement visual or acoustic cues helping the user to find and understand possible ways of interact with specific objects.

Typically, industrial AR applications are to be integrated into the engineering design process and require connections and interfaces to the existing main system pillars such as CAD, PDM, PLM or ERP systems.

Fig. 14.16b depicts data sources together with data processing efforts before auxiliary relevant information is displayed effectively in the AR device. Beside the simplification of parametric CAD data towards tessellated visualization geometry, it is important to keep in mind, that the use of AR e.g. in the context of virtually augmented training also typically requires a newly referenced product data structure.

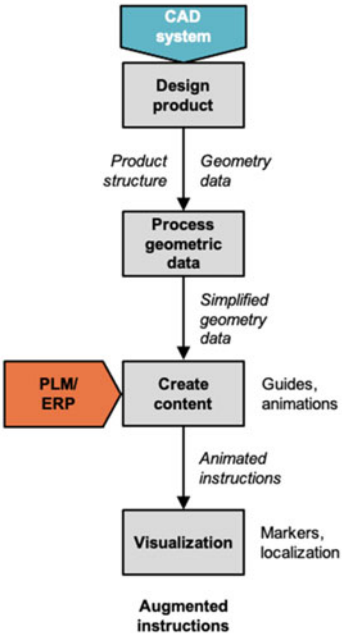
(a) **Engineering aspects of augmented reality applications**



The *behavioral* component represents the view of the user and the user interaction with the application, while the *constructional* component represents the view of the developers.
An interactive system with high usability is both useful and usable.
Useful indicates that the system supports tasks that users need to accomplish as part of some larger context. *Usable* indicates that users can utilize the AR system with minimal effort.

(b) **From commercial CAD systems to an augmented reality system**

One of the most important industrial applications of AR enables to assist manual work. AR is well suited for complex, short manufacturing operations or in customized production factory environments. Guiding humans with AR solutions becomes increasingly important. AR can also reduce assembly times and accelerate learning of the assembly tasks.



- Geometry data and product structures are derived from CAD data and PDM environments according to functional needs.
- Original product structure remains intact with *respect* to part models. Product structures, however, do not conform to assembly sequences of real parts at the assembly line.
- Assembly structure and work sequence have to be re-configured. The assembly structure and the geometric models are taken into content for the assistance of the assembly task. Auxiliary related information (e.g. guidelines etc.) is extracted from the PLM or ERP environment. Animations are created to show and demonstrate in which sequence and 3D trajectory components have to be assembled.
- Animations are played based on markers or other tracking technology applied in a real augmented environment.

Fig. 14.16 Advanced technologies in AR

With the input of ERP systems, the AR content needs to be enriched and reconfigured according to processual information to create training animations

14.7 Technological Limitations to Overcome

Major development efforts are ongoing to overcome some usability limits, such as the form factor, limited field of view as well as display resolution, battery lifetime, processing performance, hardware weight and ergonomic shape [18]. For the everyday use with CAD objects out of a PDM system, the preparation-effort still leaves space for improvement. This can be at least partially traced back to the growing diversity of platforms that go along with incompatibility due to the lack of non-standardized software formats [19].

As with Virtual Reality (VR), a common problem of current AR devices is the *Vergence Accommodation Conflict (a human perception issue)*: the way that the lenses of human eyes focus on an object is very different from the way that human eyes physically aim themselves at the object the user is trying to focus on. Such phenomena lead to experience disturbance due to nausea and fatigue caused by divergences from physical laws.

A totally different challenge is given by the practical use of AR technologies in industrial and business environments: especially in product development and manufacturing, corporate security issues have to be dealt with in an appropriate manner (to avoid espionage and leaks of intellectual property). While engineers or workers are wearing the devices during long tasks at work, during important meetings or for communication, the use of camera, microphone and other accessible sensor data does not only go along with chances, but also with risks. Security risks exist e.g. in the case of using “sniffing” (network) malware or AR data streams in order to obtain intellectual properties concerning design features of future products, functional parameters of prototypes and/or engineering process knowledge.

Today, many industrial devices have radio connection to the outside world. Due to limited bandwidth and imminent interferences with high-priority systems on the shop floor, security and malfunction issues are to be conside red organizationally.

14.8 Summary of the Technology’s Benefits and Main Trends

Overall, AR has high future potential for industrial use because the real world can be perceived simultaneously with helpful digital features. The new technology offers a wide range of potential benefits: context-specific visual support of tasks (e.g. maintenance and servicing), timesavings (e.g. by eliminating intense information searching by technicians), cost savings (e.g. by reducing training expenses and saving paper-based documentation), quality enhancement (e.g. by visually checking work steps), or worldwide availability of experts e.g. via AR-based remote systems.

Especially AR HMDs seem to be a technology with growing relevance for industry due to its scalability, mobility and the benefit of operating it hands-free. Continuous advances in hardware or marker less tracking algorithms further increase usability and flexibility.

Especially with a view to affecting peripheral technologies such as the advances in the sector of 5G, remote rendering as part of cloud-based computation will enhance the AR technology in a substantial manner and path its way towards further disrupting the engineering sector.

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