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General Requirements for Industrial Augmented Reality Applications

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Abstract

Augmented Reality is ascribed a great potential for many fields of application. Although Augmented Reality applications have been used successfully in medical or military contexts for many years, industrial applications are often perceived as isolated solutions that are only applicable in a defined and static work environment. This contribution matches general requirements for Augmented Reality applications with two case studies from an industrial context: an Augmented Reality-based assistance system for wind energy service technicians and an Augmented Reality-based welding simulator for education and training purposes. The authors critically discuss the applicability of these general requirements in the context of the case studies. Specific requirements can be identified for Augmented Reality applications that are caused, among other influences, by the variance of products and processes, work conditions, data connection issues as well as media literacy and technology acceptance. In both case studies, the authors identify approaches to meet the requirements for successful applications of Augmented Reality solutions in industrial scenarios.

Keywords: Augmented Reality, Maintenance, Training Simulation, Simulator, Industrial Application

1. Introduction

Augmented Reality (AR) is a technology that has been subject to research since multiple decades [1]. Commercial applications of AR in industrial areas have also been previously discussed [2]. Recent innovations in wearable computing and the wide distribution of smartphones have revived the topic and sparked the development of numerous new applications (Fig. 1).

The technology is expected to perform well in the future, especially towards the development of intuitive human-machine interfaces [3]. The International Data Corporation predicts an enormous market growth from 0.2 bn. USD in 2016 to 48.7 bn. USD in 2021 [4].

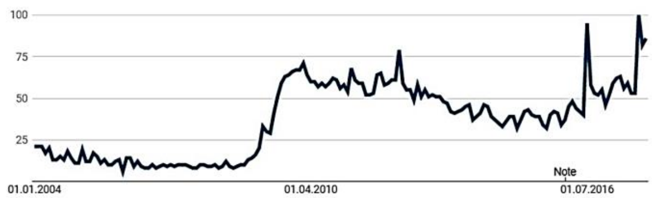

Fig. 1. Normalized google-trends analysis on the term “Augmented Reality”.

In spite of the depicted trend, current applications in the industry sector are often characterized as proprietary [5], [6]. Especially the transfer from a laboratory environment towards industry is considered to be inhibited by specific requirements [7]. Contrary to widely established applications in areas such as aviation or medicine, industrial applications face synchronized workflows, harsh environments, specific labor agreements, and ergonomic requirements [8].

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This paper strives to provide a structured overview on the general requirements towards AR applications in the industrial sector based on a literature review (section 2). Particular emphasis is placed on conditions and requirements that hinder applications and are specific to the industrial sector. The findings are validated through two case studies from industrial applications that concern the application of AR to support mobile maintenance processes (section 3) as well as the training of welders (section 4). In section 5, the authors discuss specific requirements of industrial AR applications.

2. Related Work

This section covers a collection of existing industrial applications of Augmented Reality (AR), as well as the related general requirements from literature.

2.1. Industrial Augmented Reality Applications

The description of industrial AR applications aims to support the deduction of general requirements. Therefore, a wide span of industrial applications is covered, but they are by no means exhaustive. Industrial AR applications are expected to perform well in the following areas:

- **Product design:** Visualization of interactive 3D-models in prototyping and presentation [9].
- **Plant design:** Visualization of a planned layout within a real factory environment [9].
- **Training:** Augmented training simulation or optimization of production processes in real environments [10].
- **Production assistance:** Virtual assistance system through visualization of context-sensitive information on production processes, manual assembly and products at the shop-floor level [9], [11], [12].
- **Quality assurance:** AR-based assistance through visualization of sensor data or fault management information [12], [13], [14].
- **Production logistics:** Support of indoor navigation through AR-based guidance [15] or information on picking processes [16].
- **Remote maintenance:** AR-based remote connection for the support of maintenance staff on location, teleoperating maintenance robots [17] or allocation of interactive and virtual instructions during the maintenance of production facilities [9].

In addition to the applications, some authors also describe specific barriers and requirements that have been observed during development and testing. These hindering factors are compiled and complemented within the next section.

2.2. General requirements towards AR Technologies in Industrial Applications

This section covers general requirements of AR applications for the industrial sector. The description follows a cross section approach of industrial AR applications. The requirements are structured by dimension of time (development and integration, set-up, operation).

Requirements during development and integration

- **Cost-effectiveness:** The expected return has to justify the expense that is required during development and integration, respectively the investment costs of the AR application [8].
- **Data security:** If data recording or position tracking leads to a surveillance of employees, certain laws or regulations apply, and may create conflicts with workers and their councils. Therefore, any collection of data should be agreed upon and data security has to be guaranteed [18].
- **Applicable regulations:** Regulations, such as work safety regulations or hygiene specifications, are to be considered during the design and integration of AR applications [19], [20].

Requirements during set-up:

- **Set-up time:** The time required for the set-up of AR applications within the industrial environment should be minimal [9]. This might include necessary recurring processes, such as calibration or cleaning [21].
- **System reliability:** The application should require minimal maintenance and be as reliable as possible [9].

Requirements during operation:

- **Accuracy of presentation:** Precision in the alignment of real and virtual objects is necessary to reduce possible errors [21].
- **Real-time capability:** Tracking and visualization of objects should be performed in real-time in order to allow a more intuitive interaction with the application, and reduce risks of errors or motion sickness [21], [9].
- **Ergonomy:** AR applications usually operate on the human side of a human-machine interface. Their design and operation should therefore be human-centric and consider certain human factors [22], [23], such as reduced attention or eyestrain during longer times of operation [21].

The presented requirements have been collected with a cross-application approach and show a rather low level of detail. This does not limit them to the industrial area, so that they instead may also apply for applications in other areas, such as flight simulators. Therefore, these requirements and their specific dependencies are discussed and detailed in two case studies with industrial AR applications.

3. Augmented Reality based assistance system for wind energy technicians

The developed AR assistance system assists mobile service teams in carrying out maintenance on wind energy turbines. A typical application in this context is the inspection of electronic components. The service technicians record values of components on defined service points in the wind energy turbine based on a maintenance protocol. To carry out the measurements, the technicians need the associated circuit diagrams of the wind turbine. The measured values and, if necessary, further comments on condition or defects of the components are documented in the maintenance protocol.

Figure 2 shows the system architecture divided into three areas: connection to the back office, data storage and AR features. The back office prepares maintenance orders and provides the order-related documents. In the data storage area, order data and processed orders are held in a web-based data management system. The AR features area is divided into the AR assistance system on a tablet PC and the AR application on data glasses. Due to work process and data security requirements, the service technicians use these two mobile devices to fulfill maintenance orders in the field. The AR assistance system supports the service technicians in:

- Navigating through the maintenance process based on the main components of a wind energy turbine
- Processing individual work steps by providing process-relevant information on the data glasses
- Providing virtual, auxiliary materials for carrying out individual work steps
- Documenting measurement data and performed maintenance processes.

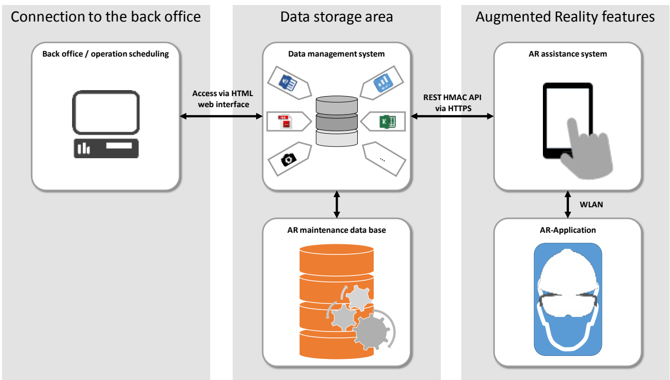

Figure 2: AR maintenance system architecture [24]

The general requirements for AR applications identified in Section 2.2 were taken into account in the system development as follows and the fulfillment of each criteria is assessed in figure 2.

The **cost-effectiveness** is based on the anticipated efficiency improvements, e.g. time savings, of the service teams supported by mobile assistance systems in the maintenance of the steadily growing number of wind turbines. The used AR hardware is comparatively cost-intensive, but due to the dynamic market development in the sector, a rapid cost reduction in the following years is assumed.

The **data security** requirements for data transmission are met by security features in communications between enterprise IT-systems and the mobile assistance system, asymmetric encryption, and REST (Representational State Transfer) interfaces with HMAC (Keyed-Hash Message Authentification Code) authentication. Due to the offline operation of the mobile system, the data security requirements are considered to be well fulfilled.

Considering **applicable regulations** has been of particular importance in the development of the AR-based assistance system. Here, the requirements specifically apply to work safety, both, in terms of hardware selection and software development. Therefore, the development team surveyed and analyzed the work process of the service technicians. Current AR hardware cannot completely fulfill the requirements of the work environment, especially regarding occupational safety regulations for hardware.

The requirements for **low set-up** times, easy implementation and high **reliability** of the system has been achieved by a calibration free marker-based control, intuitive user interfaces, e.g. gesture control for the data glasses, as well as work process-oriented user surfaces. Regarding system reliability, software and hardware proved very reliable in the laboratory and field tests. AR hardware needs some minor improvements for a permanent application, e.g. a higher battery capacity.

The **accuracy of presentation** has been achieved by a marker-related representation of virtual objects that proved suitable for the field of application. For future applications, the development team aspires to develop markerless positioning of virtual objects that save the effort for the marker equipment.

By deploying current high-performance AR hardware with a predefined gesture control, the requirements for **real-time capability** could also be met.

Future users were intensely involved in the development process of the assistance system to ensure the consideration of the users' needs in regards to **ergonomy** of software and hardware system components. Through the development phase, hardware and software tests with service technicians in the field of application were conducted to ensure a user-centered solution. By integrating the AR hardware into a safety helmet, the requirements regarding wear comfort could be fulfilled. The limited field of vision is a general weakness of the currently available AR hardware that fulfills performance requirements.

Figure 3 recapitulates the fulfillment of the criteria for the AR-based maintenance assistance system for wind energy technicians based on the aforementioned findings. On a scale from a very poor to a very good fulfillment, the individual degree of fulfillment has been rated in collaboration with developers and test users based on the experience from system development and field testing.

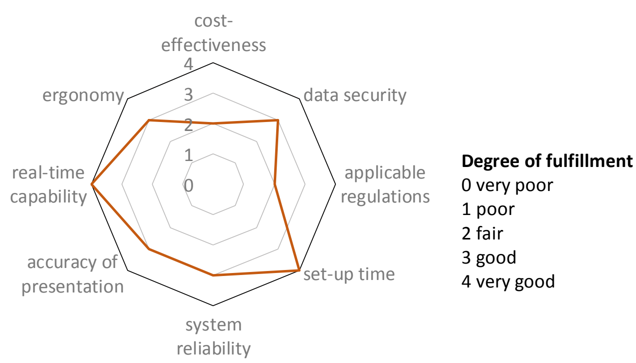

Figure 3: AR assistance system: Fulfillment of general requirements

4. Augmented Reality Training Simulators for Welders

The Soldamatic training simulator for welders (Fig. 4) focusses on manual welding processes and is a commercial product sold by Seabery Soluciones SL [25]. The hardware consists of a computing unit that is embedded in a welding equipment casing; a welder's helmet that holds cameras, speakers and an integrated display; attachable hand-held devices for MIG/MAG, electrodes, and GTAW welding processes; a stand; and multiple standard work pieces that are made out of plastic and are printed with reference markers [25].

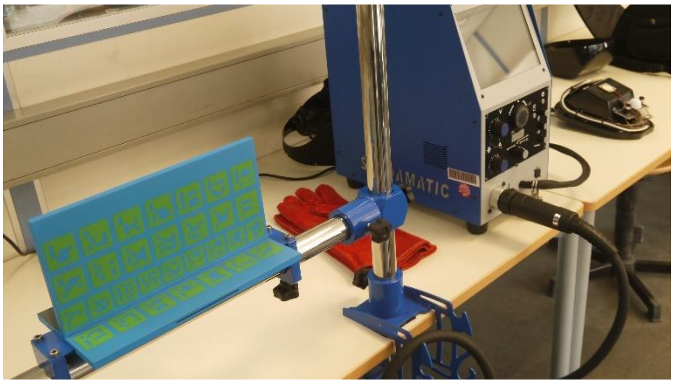

Figure 4: Training simulator for welders

An optical tracking system is applied to obtain the relative position and orientation of the hand-held devices and the work pieces. The simulation reacts to the handling and creates a welding arc, bead, and a metal texture that are displayed over the workpiece.

The applicability of the system has been observed in two application scenarios. These encompass a joint training organization as well as the training division of a car chassis manufacturing plant of a German car manufacturer.

Cost-effectiveness is among the key factors that led to the investment in the described training simulator. The investment is financially justified by comparison towards the costs of an expansion of the existing welding booths as well as lower running costs through savings in resources (metal, inert gas, electricity) compared to conventional welder training. The amortisation period highly depends on the considered factors, but it is expected to span between one to three years.

Objections concerning **data security** were raised by few welding trainers, but caused significant difficulties on these occasions. Initial issues revolved around job security and mistrust towards the employer, which were coupled with the possibility to utilize the simulator for a performance measurement of the trainers. The simulators measure and record performance and time of work, which is strongly rejected by some trainers.

Applicable regulations on work safety represent no problem, because the training is performed in a stationary workspace with reduced possible hazards compared to the conventional process. The intended use doesn't include any performance measurement or recordkeeping on the trainers' work, however the workers' council should be informed about the functionalities. Another issue is the integration of the simulation into the welding training curriculum, which is an ongoing subject of research [26].

The **set-up time** is significantly shortened in comparison with the conventional welding process. A training session can be configured or restarted within seconds, whereby a conventional process would include the preparation and refurbishment of the workpiece and workplace.

The **reliability** of the simulator is depending on the welding process. Whereby the MIG/MAG simulation is highly reliable, image recognition while working with electrodes and the GTAW torch is easily interrupted by change in lighting conditions. The problem is caused by the low resolution of the embedded camera system, which necessitates a precise calibration in order to recognize a set of three light-emitting diodes that are positioned on the welding material. Both application scenarios apply the simulation for all supported processes, but also have created a work environment that is shaded from sunlight.

A professional welder, without further knowledge about the simulation, usually requires multiple attempts to achieve a good score with the simulator. This is caused by discrepancy between the simulation and a real welding process and a limited **accuracy of presentation**. However, both application scenarios reported good progress with the training simulation. It was stated that experienced trainers are more open to adapt the new devices, when they are characterized as training equipment without a claim to a perfect reproduction of real welding processes. The display size is similar to the field of view in an actual welding helmet and its' image quality and the alignment of real and virtual objects have no negative impact on the training sessions.

The simulation is computed and displayed in real-time, which is necessary for an authentic look and feel. **Real-time capability** is also provided to continuously give feedback during the training sessions.

Ergonomy requirements are met by the simulator through a high physical fidelity. The simulator applies original welding torches and the case for the computing unit is based on original welding equipment. The selections are made with a clickable rotary knob, whose dual functions sometimes cause selection errors. Also, the camera system is positioned about 10 cm in front and below the eyes of the trainee, which complicates orientation. However, simulator sickness has not been observed within the application scenarios.

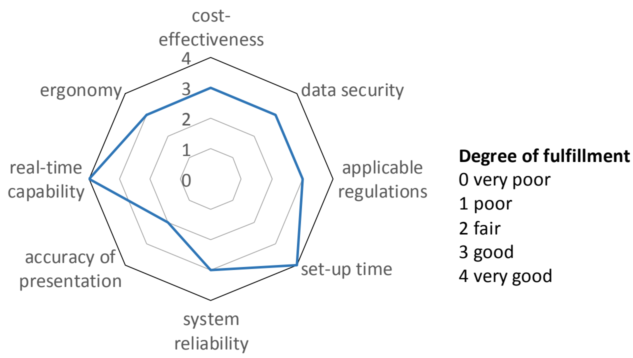

Figure 5: Welding simulator: fulfillment of general requirements

The assessment of this commercially available AR application towards the refined scale is depicted in Fig.5. The fulfillment of the criteria is derived from the described observations made during the application scenarios.

Additional findings, as well as a comparison of both applications, are described in the following.

5. Discussion of Specific Requirements

The discussion encompasses several issues that have been observed in both case studies and that are expected to be specific challenges towards AR applications within the industrial area.

Variance of products and processes

Particular challenges in the maintenance of wind energy turbines consist in the heterogeneity of plant types and components, which requires service technicians to have a wide range of expertise to perform maintenance activities [27]. Related to AR features, the preparation of technical documentation for display on an AR system has proved as a particular challenge. These documents are currently not suitable for display and manipulation without manual revision.

The welding simulation is limited to a predefined set of standard workpieces. Although the integration of individual workpieces is a strongly desired feature, it requires considerable development effort, which leads to additional costs and cannot be performed instantly. On the contrary, an adaptation towards individual processes is rather simple, since welding position, parameters and environment can be chosen almost at will, considering a certain angle and distance of view, as well as stable lighting conditions.

Working conditions

In the maintenance of wind energy turbines, the working conditions are physically very demanding and safety-critical. In this context, the AR hardware used is exposed to the influences of the rough working environment, e.g. dust, dirt, shocks or abrasion. Service technicians have to wear personal protective equipment to carry out the maintenance work. This includes a climbing harness and a protective helmet. The consideration of these factors is of vital importance for the AR hardware selection and the assistance system development.

The welding simulator system is embedded in a relatively stable casing and helmet. However, it has to be used in separation from the real welding booths, as it does not respond well to splatters of liquid metal and high temperatures. Additionally, stable lighting conditions are required.

Data connection

Another application-related challenge has been a missing or unreliable data connection at the locations of the wind energy turbines. Therefore, the assistance system has been designed to operate completely offline, if necessary.

A connection to the server is not a problematic issue for the welding simulator, because it is designed to be a stationary system. The problem lies within the reliability of the optical tracking system, which highly depends on ideal lighting conditions and a stable angle of view and distance between camera system, workpiece, and handheld equipment.

Media literacy and technology acceptance

Regarding the development of the AR features, the inclusion of novel interaction patterns in connection with data glasses, such as gesture control, has been challenging for many users. Especially the imparting of functionalities and implementation potentials to the service technicians of these unfamiliar technologies has been challenging for the development team.

Technology acceptance towards the welding simulator is mainly hindered by mistrust towards the employer. This is articulated as anxiety of facing excessive demands, being replaced or monitored. An individual user training to convey functionalities and purpose of the simulation system to the trainers can circumvent this.

6. Conclusion and Outlook

Compared to already established AR applications in the fields of medicine, military or aerospace, industrial AR applications have specific constraints that can lead to application barriers. The general requirements for AR systems outlined in Section 2 can be met to a large extent for the applications considered, but there is still considerable room for improvement. Especially with regard to the reliability, fulfillment of work safety regulations and overlay accuracy of the systems. This is mainly due to the current AR hardware used for the applications considered, which does not yet have a high degree of technological maturity. The cost-effectiveness of the AR systems can only be reached by time or resource savings, due to the comparatively high costs of capable AR hardware.

In addition, requirements have been identified within the scope of the presented applications, which apply in particular to the development of AR systems for industrial use. Here, approaches are presented to address the identified barriers of industrial AR applications. However, it can be assumed that, in addition to the general factors, specific requirements must be taken into account for each application. The current dynamic development of AR technology is likely to lead to new applications and new requirements as technologies evolve.

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