Title: Industrial Augmented Reality Applications

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1. Introduction: Augmented Reality in an industrial context

Bringing research results out of the laboratory and into an industrial context is always a challenge. If this process eventually leads to success on the market it is usually called innovation.
Innovations in the technological area of augmented reality are rare. It has to be considered, that research and development (R&D) is still in its early days. However, the academic and industry partners both agree that there is huge potential for the technology in a broad variety of applications. As a result various attempts to bring R&D and "real world use" of AR together have been made and are still top of the list for potential innovations.
Reviewing the research literature in Augmented Reality over the last couple of years leads to the impression of a variety of applications in the field. In contrast having a look at the industrial and commercial market AR applications are barely found. Because of the maturity of AR applications we rather opt for more precise descriptions of projects presented.
We introduce a classification approach embedding demonstration systems, prototype systems, and productive systems as the main types of AR systems. Each of these types has its own advantages and disadvantages and all of them are necessary to establish AR as an enabling technology. Criteria and a discussion of characteristics are given to identify the appropriate type. The different types and conglomerates of types are illustrated with practical examples and are discussed in certain detail.
We will start with highlighting the background of industrial AR applications followed by the approach to define the term IAR applications.
Then we propose three main categories on a maturity continuum, illustrate these categories with a variety of examples from international IAR R&D. Based on these classifications we will illustrate and discuss in detail three of our own projects.
Finally, we will conclude with some lessons learned from our experience to give some advice or guideline for industrial AR research and development.

2. Background: Reported Industrial AR Applications

There are three driving forces in any industrial context, which lead to the introduction of new technologies: cost reduction, speed-up of processes, and quality improvement. If one can bring the appropriate information at the right time at the right place all three forces can be addressed. Augmented Reality seems to be an ideal candidate in almost any context. It lies in the very nature of AR to be applied within the current working context (e.g. the assembly line) and to deliver accurate, useful, and up-to-date information (e.g. the number and representation of the next product part to be assembled). This will

eventually lead to shorter production times, less training efforts, the reduction of errors, and finally to lower production costs.
But, why is it so difficult to implement AR technology in an industrial context? We believe that the maturity of the contributing technologies (tracking, displays, content generation, wearable computing, etc.) does not suit the demanding industrial environment conditions yet regarding robustness, reliability, quality, and practical experience. But, we also believe, that it is very close to be applied successfully in a broad range of fields.
It can be said that the application of augmented reality in an industrial context started with Boeing's wire bundle assembly project in the early 90's (see Mizell, 2001). The wiring for each individual airplane to be built is unique. Therefore, the wire bundles needed to be pre-configured in a workshop beforehand according to plans displayed on large boards in huge numbers. The display of the wiring paths for this very manual task of forming bundles at the boards seemed to be a promising area for the application of AR technology: the wire plans are augmented directly onto the board using an optical see-through head-worn display. Even if this application did not make it into the real production process for various, mainly organizational reasons, the wire bundle assembly still stays as the first prototype example for industrial AR.
This project was followed by several smaller projects until the end of the last century. While numerous academic projects evolved in the following years, industrial augmented reality (IAR) applications are still rare. In some cases, AR technology was applied successfully in certain use cases. For instance in supporting welding processes (Echtler et al., 2003), where the welding helmet itself is used to overlay information and to ease the visibility of the welding point and seam.
To date there have been two major initiatives for AR innovation. The Mixed Reality Systems Laboratory in Japan, with its focus set on the development of mixed reality prototype applications comprising hardware and software, has demonstrated the potential for the real-world use of AR (see Tamura, Yamamoto, & Katayama, 2001). The success of this project led to the release of the mixed reality platform, a comprehensive toolkit consisting of display, tracking, and AR software technology.
The other initiative has been the German project "ARVIKA" lead by Siemens which included the majority of the manufacturing industry in the country as well as selected partners in academia and small and medium enterprises (see Friedrich, 2004). The focus here was on the application of AR in the fields of design, production, and servicing.
There is noticeable progress in the application of all kind of augmented reality technology in a broad scope of fields. For instance the use of projection-based augmented reality in the context of museum exhibitions by Froehlich et al. (2005), where a permanent installation at a German exhibition clearly shows the reliable use of AR technology. Another example being the use of head-mounted display based AR technology in the education of students at TU Vienna reported by Kauffmann (2005) with major benefits for students in understanding complex geometric properties by applying interactive techniques.

The European Commission currently supports a variety of projects related to augmented reality in its framework programs (Badique, 2005), which is a strong indicator for the importance of the dissemination of this technology
In the realm of industrial augmented reality applications, Navab (2004) identified design, commissioning, manufacturing, quality control, training, monitoring and control, and service and maintenance as main application field for augmented reality and gives guidance based on own experiences made. Navab emphasizes the need for “killer applications” to progress further the research and development in IAR applications. He, for instance, overlays images, drawings, and virtual models onto the geometry of plant equipment, in particular industrial pipelines with high accuracy.
All projects encountered serious problems regarding the instrumentation of the industrial site with tracking equipment to track the user’s position and orientation, several calibration issues, and the robustness, ergonomics, and fidelity of the AR display technology, among others.

All these initiatives brought forward various prototypes and demonstrated applications and have therefore been valuable in progressing the field of AR. The lessons learned in these projects have had a strong influence on the direction of AR R&D worldwide.

3. Definition and Scope of IAR Applications

The term “Industrial Augmented Reality Applications” is used in the literature in a very broad context. As far as we have reviewed the related work there is no clear definition of the term used neither of the scope.

Definition

We will address this problem by giving a preliminary definition, dividing the term into its components “industrial“, “AR”, and “applications”:

“Industrial” refers in one way or the other to an organized action of the making of goods and services for sale and therefore differentiates itself from e.g. entertainment, medicine or education.

“Augmented Reality” was often defined in different ways. Either a more conceptual point of view has been taken (which could also include very different media and even dreaming) or emphasis has been placed on a technological point of view, which often refers to the display or tracking devices used (ranging from context activated information display on a Personal Digital Assistant to projection systems applied to real world geometries). In this article, we will rely on a definition of Azuma et al. (2001) which is widely acknowledged and can serve as a benchmark for what AR includes and excludes:
“we define an AR system to have the following properties:
- combines real and virtual objects in a real environment;
- runs interactively, and in real time; and
- registers (aligns) real and virtual objects with each other.” (p. 34)

The most difficult part in trying to give a precise definition of IAR applications lies in the last word: what is an application? Can one talk about an application if the system presented is running on a computer and is not only described with formulas? Then again, can one talk about applications if and only if there is a market success of such a system?
It is often confusing for the reader to decide, whether the system is applicable in his or her targeted context based on the descriptions given. To overcome this problem we provide a simple classification system on a maturity continuum. Before we describe this classification we will define industrial AR applications in the following way:

Industrial augmented reality applications are systems to be used in a product lifecycle process utilizing the concept of spatially aligned and interactive overlay of computer generated information in a working context.

With this definition, there is still sufficient room to define the kind of application, which we characterize in the following section:

AR Applications Maturity Continuum

Reviewing the recent literature on AR applications regarding their maturity or applicability is a difficult task. We are introducing a classification system that places three main types of applications on a continuum of maturity and innovative character: Demonstration Systems, Prototype Systems, and Productive Systems (see figure 1).

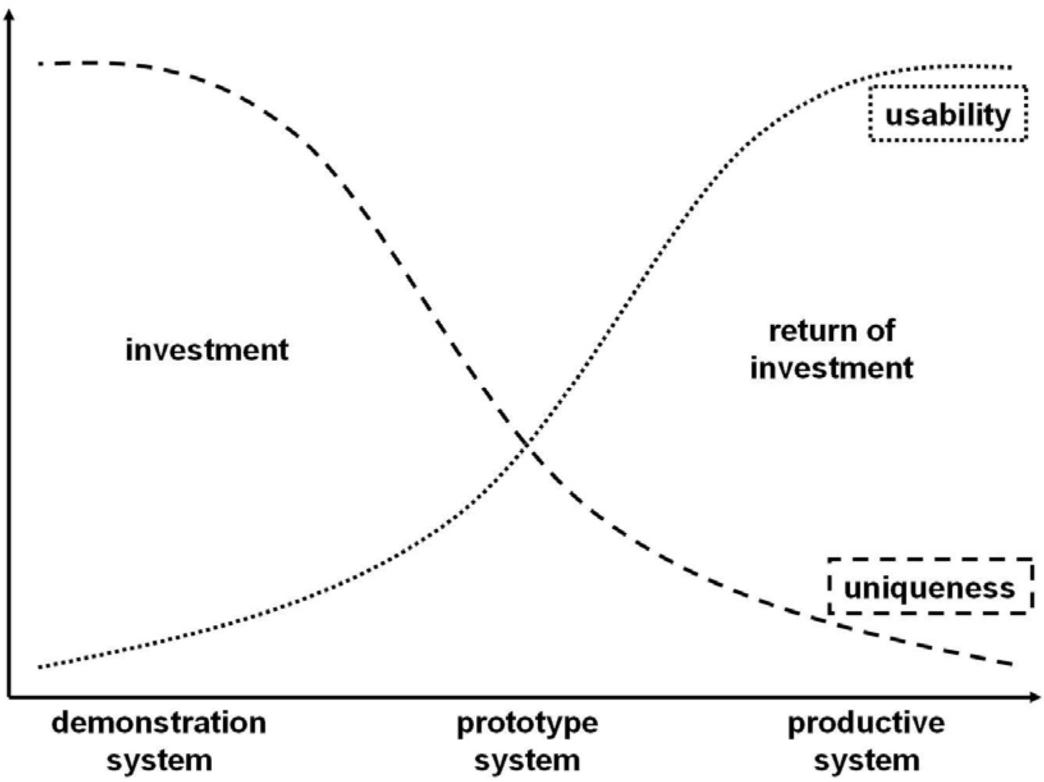

Figure 1: Types and Maturity of Applications

The main characteristics of a **demonstration system** can be outlined as follows:

- It has to be novel or unique in some way. This is the strongest benefit and the biggest challenge. If the system is demonstrating existing technologies or approaches only, it is probably not worth to be published or reported and therefore will be probably rejected by most publication bodies for good reason. While a productive system has to have a unique selling proposition, a demonstration system has to have a unique research or invention proposition. An excellent example for a unique demonstration system is the introduction of tabletop marker-based Augmented Reality by Kato et al. (2000). The main purpose is to explain concepts and ideas.
- It focuses on a single or few aspects to be shown in comparison to the provision of a comprehensive application solution. It shows the benefits of the technology rather than of the real use case.
- It is often a prerequisite to approach or convince customers and users. Highlighting some central aspects demonstration systems motivate customers to invest further into augmented reality research or development. Potential future users can benefit from demonstration systems in getting a first idea about possible use cases. Because these systems do not actually solve a real world problem it is mainly up to the user to imagine possible application scenarios, which can be a very contributing factor because it involves users from the very beginning. It is a required, first step in the innovation process.
- It is not targeted for real users. The developer or presenter is the user of the system. That's why almost no documentation is needed.
- Hardly ever it will be replicated: the demonstration system is a dedicated, proprietary solution and should not serve as a technological basis for further development. It has a short life cycle regarding usage and development.
- The provision of prepared data/content is sufficient. It is neither required nor reasonable to invest much time and effort into the integration of existing real-world content. Rather information out of a possible actual working context are taken as a basis for the preparation of a convincing demonstration scenario.
- It is applied in laboratory-like, demonstration-friendly environment that can be the place where the system was developed or a conference, exhibition or fair.
- These types of applications require investment and will not provide immediate return of investment.
- It does not have to comply with any standards (except for systems demonstrating standards) and does not need to fit into existing organizational or workflow processes.
- The main targets are customers and technologists, who are going to introduce or implement AR technology. The needs of users are of interest only insofar as the customer understands them. This statement might look a little paradoxical, but it reflects the (sometimes very) different motivation and scope of work of customers and users.

A **prototype system** can be characterized:

- It has to show unique or new properties or features in comparison to existing products or solutions. Mainly based on the knowledge and findings of demonstration systems (own and others) the uniqueness lies in the application of these findings in a "close-to-real-use" context. It is a required step before a potential productive system development
- Therefore the focus is set on an application scenario and work context rather than on the technology itself.
- It involves (few) real users and with this allows for first usability investigations.
- Because the developer or presenter is no longer the only user, some documentation and self-explaining user interfaces are needed.
- Requires a certain (often underestimated) amount of development time
- It is used and applied more often than a demonstration system and has to be robust in its core functionality.
- Makes use of and integrates real-world data, even as example data sets only.
- It has to comply with existing work processes in those aspects to be investigated.
- It can be used in the laboratory or another technology-friendly environment. For instance, a prototype system is installed first at one work place in a plant, where it does not interfere with the existing workflow and where the environmental conditions are safe and controllable.
- The prototype tests concepts in reality context.
- The targets are customers and users, because real users are confronted with the system. But still, the customers (e.g. the management) have to be convinced to invest further into AR technology.

Finally, a **productive system** can be described in brief with the following:

- It addresses real users, which are very often unknown. While in the process of prototype testing a face-to-face contact between developers and users is given and needed, here the system will be delivered to users never seen before.
- Therefore, documentation and well-designed and tested user interfaces are essential.
- It has to be integrated into existing data chains and working processes.
- It has to be robust and reliable.
- It is applied in the "field", often in very harsh environments (see description of example below)
- It has to be profitable; this is the main reason for a product. There has to be a market.
- The use of standards (technological, organizational) is mandatory and it has to fit into the technological environment (operating systems, middle-ware, hardware, network infrastructure, data interfaces, GUI guidelines, …)
- The acceptance is a main issue, the main targets are the users.

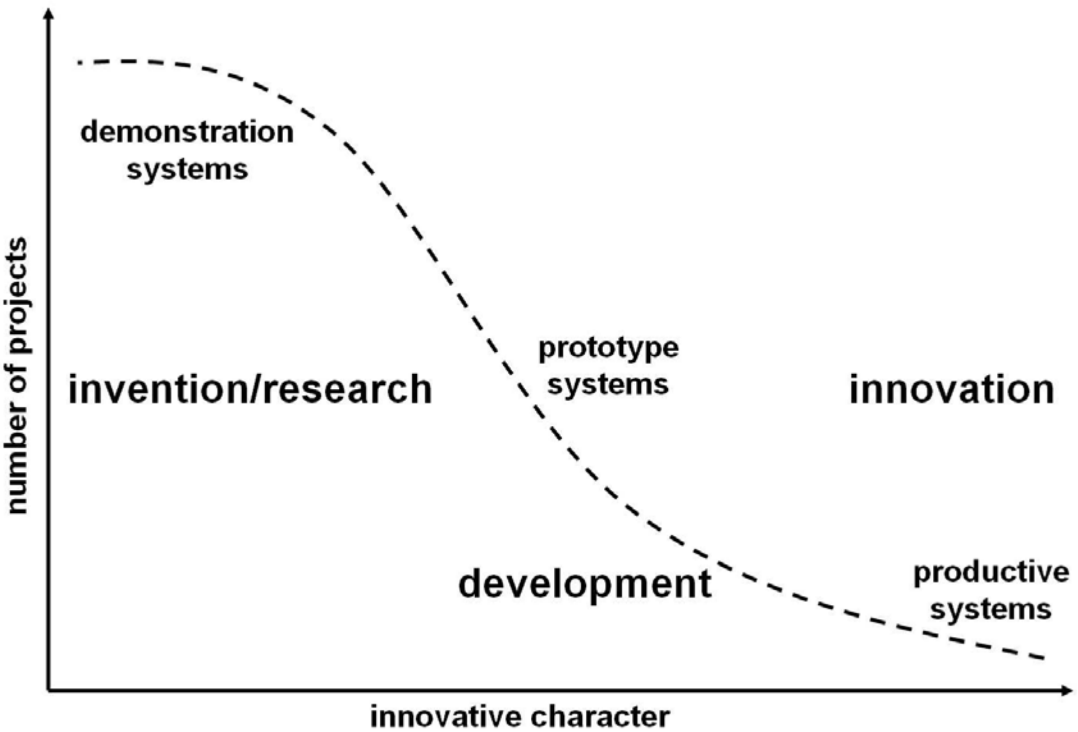

Figure 2: Relation between types of applications

Given the characteristics described above it is obvious, that (1) only a small number of AR projects will comply with the requirements of a productive system as the main result of the innovation process and that (2) we need a huge number of demonstration and prototype systems as a prerequisite for successful innovation. This is illustrated in figure 2.

4. Illustrating Examples

To make our classification approach a bit more tangible we will show with three of our own projects the commonalities and differences in the types of AR applications. We chose own projects, because (1) we do have in-depth knowledge about these and (2) it is easier to highlight flaws in comparison to criticize the work of other researchers or developers in the field where only the reported descriptions are available.
We will describe exactly one example, for each of the three types. These application examples are part of (Regenbrecht, Baratoff, & Wilke, 2005)

Demonstration System: Servicing and Maintenance

Today's products are getting more and more complex. The days when a plan of the electrical circuits of a car fit onto one large sheet of paper have long gone, modern high-tech cars now require a database system and state of the art computer equipment for electric and electronic diagnosis. A printout of such a database is as thick as an encyclopedia.
How can one bring the right information to the right place at the right time? The use of augmented reality technology seems to be obvious. The service personnel is equipped with a (wearable) computer unit and gets the appropriate information displayed next to or overlaid onto the object being

inspected. Not only can this do away with the need for a paper schematic, but a far richer information resource can be provided via online access to dedicated information and multi-media content. The promise is to increase effectiveness (fewer errors) and efficiency (shorter time to complete the task) through the use of context-sensitive, up-to-date, and media-rich information. All major manufacturing enterprises are thinking about how to make use of AR technology in their maintenance and servicing areas. The more complex the product is, the greater the potential benefit of AR.

For the diagnosis of maintenance and repair tasks, modern cars provide a system interface (mostly via a plug-like connector). While this interface allows for very fast and precise analysis of the state of the engine, the accompanying information is still found on a dedicated PC or on print-outs. Hence, the object to which the diagnosis is applied (part of the engine) and the resulting data yielded by the diagnosis are spatially separated. AR has the potential to close this gap, enabling the diagnosis results to be displayed right in immediate proximity to the engine.

There are many important questions that must be considered, however: What kind of information is useful, and should it be represented? What are the technological alternatives available for solving this? If the data is very complex, as it often is, where and how do you place the information at the engine?

These were the issues we had to address when implementing a demonstration system for a real Mercedes-Benz (8 cyl. SL) engine. A head-mounted display solution connected to a portable PC (alternatively, a notebook computer) was chosen. The tracking of the user's position and orientation was done by using a marker-based approach. In this case, markers were attached to a U-shaped object, which was placed into a certain location at the engine. The use of multiple markers at well-defined positions provided us with reasonably precise tracking.

The following data types were presented (see figure 3): (1) Maintenance and repair instructions taken from the garage information system, represented as textual and pictorial information in space. (2) Pre-recorded video instructions in the form of a "virtual TV set" placed at a fixed position in space. (3) 3D models with predetermined animated sequences as overlays. And (4) a video/audio link to an expert technician as an example of remote technical assistance displayed with the TV set approach.

While the choice of computer and display technology is straightforward, taking into account such matters as cost, quality of design and reliability, the information provision is a bigger challenge due to various key factors. (a) The appropriate information has to be selected automatically out of the existing information system (normally text and graphics with references to 3D models), (b) the user interaction has to be supported in an easy-to-use way, (c) new multi-media content (esp. video and 3D models) has to be created and edited, and finally (d) the multi-media information has to be brought into a spatial relationship with the object (engine). This entire authoring process is subject to research and development (see Haringer & Regenbrecht, 2002) and clearly deserves stronger attention.

Figure 3: Maintenance Demonstration System

Although the application scenario looks obvious and straightforward, the developed system is not ready for actual use yet. It can very well serve for the presentation of the concept behind and the application potential. Hundreds of potential customers and users have seen the demonstration system at the laboratory and at exhibitions and are therewith now able to validate the applicability in their working contexts. The feedback of the potential customers led to the following main findings:

The use of a head-mounted display (HMD) can not be recommended at this stage of the maturity of the technology. Tracking fidelity, calibration issues, and display resolution and fidelity are the main reasons for this. While it is possible in certain cases to apply a HMD in a different context, e.g. display of context-activated 2D information (see productive system example below), three-dimensional, registered overlay has to be implemented in a different way.

The use of the inexpensive marker tracking is not suitable for such a real-world application yet, because (a) the instrumentation of the environment (markers at or around the engine) is unacceptable and (b) the reliability and accuracy of this tracking method is not sufficient in a garage workshop context.

The authoring process is far from being comprehensive (see above).

Nevertheless, this demonstration system clearly shows the benefits and limitations of the idea and the technology and led to follow-up projects with a shifted focus.

Demonstration and Prototype System: Visualization of volume and surface data in airplane cabins

This application allows the interpretation of computational fluid dynamics (CFD) data within a real airplane cabin (Regenbrecht & Jacobsen, 2002). The information is displayed as volumetric data in form of voxels. The setup demonstrates the combined visualization of four domains: video see-through, VR data, phantom model, and voxel data, as shown in Fig.4.

Non-visible physical properties of a real or simulated environment can become visible using VR technology. In our case climate conditions within the cabin of an Airbus airplane are displayed as spatially distributed voxel data. These data represent e.g. air temperature, velocity, or pressure. The physical

values are coded with different colors using 3D texture mechanisms available in rendering hardware today.
One main problem in interpreting such volumetric data is the loss of relationship to the real environment, for which the data sets were originally computed. Using the technology of AR the volumetric data can be spatially aligned with the real world for appropriate interpretation. Furthermore missing parts of the real environment, like seats not yet placed and compartments not yet built in, can be visualized.
Finally, we use a phantom model of (parts of) the real environment (in our case of the seats) to render the hybrid scene with the correct occlusion relations between real and virtual world.

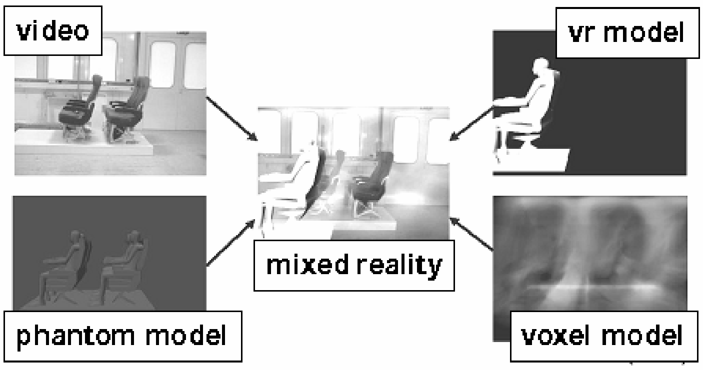

Figure 4: Principle of combined display of VR, phantom, voxel models, and video

Incrementally we have implemented three versions of the system: (1) a demonstration system at our laboratory (Fig. 5.a) , (2) a second, mobile demonstration system with a scaled-down model for presentation and teaching purposes (Fig.5.b), and a prototype system implemented at the customers site (Fig. 7)

Figure 5: a) Mockup of real-size cabin, b) Miniature cabin model

In both demonstration setups (Fig. 5 a and b) the user wears a head-mounted display with a mini camera attached to it. The main difference is the tracking system used. Setup (1) tracks the user's head with an A.R.T. Dtrack system (ART 2003) with very high quality. This system tracks retro-reflective markers within the environment by self-flashing infrared cameras. The main disadvantage is the need to place fixed cameras (in our setup three of them)

within the real environment, which is not suitable for the application in a real airplane cabin. Setup (2) uses a marker based tracking approach described in this paper. This tracking is not as accurate but more flexible. The markers are detected using the video camera already mounted to the HMD. HMD and camera are connected to a standard PC equipped with a graphics board capable of generating 3D textures.
The application allows all model domains to be switched on or off, and appropriate files to be loaded. The virtual-to-real-world calibration, i.e. the positioning of the virtual models in the real world coordinate system, is done in a pre-processing step using a special calibration tool. All data sets (CFD, VR, phantom) are pre-computed, respectively pre-modelled.
After the implementation of these two demonstration systems, we have developed a prototype system to be transferred to the customer’s factory plant. To do so, we have extended the miniature mock-up system to a real-world sized tracking approach. As in the engine example mentioned above it was not possible to instrument he environment (airplane cabin) permanently with markers. We opted for a solution, where markers were temporarily placed within the cabin (using self-adhesive markers). To do so we have researched and developed a semi-automatic self-calibration system that computes the geometric relation between these temporarily placed markers (Baratoff, Neubeck, & Regenbrecht, 2002).

The whole system, including all hardware components needed (PC, helmet with HMD and camera, video-splitter, controllers, battery operated power supply, self-adhesive markers, interaction device) is integrated into a portable unit (flight attendant trolley, see Fig. 6). It has been transferred to its final destination at Airbus Industries in Hamburg, Germany. In each session, the engineer rolls this unit into the airplane cabin, attaches markers to the environment, and calibrates the coordinate systems. After these preparatory steps, he can visually interpret the CFD data in its relation to the real world. Finally, he removes the markers and leaves the cabin.

Figure 6: Final AR system integrated into trolley

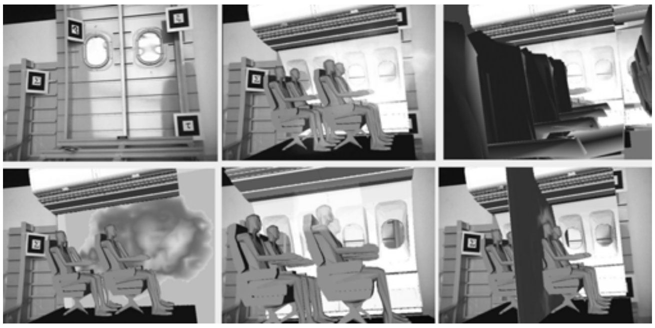

Figure 7: Prototype system in use at customer's site

Because we were using a virtual reality system as a basis for the AR system, the solution can be used for digital mock-up displays as well. Even elements of the cabin that have not yet been built in can be visualized in 3D with this system. Interestingly enough this is now what this system is primarily used for at the customer's site.

This prototype system is ready to use, but more design and engineering is needed to prepare it for long-term use. The HMD needs to be more robust and ergonomically designed, the update rate and robustness of the tracking system has to be improved, and the access to CFD and 3D model data has to be improved.

On the other hand the system has reached a stage of maturity, which allows for usability studies as well as for actual engineering tasks. Once the initial prototype test phase is completed, decisions can be made on whether a final productive system will be developed.

Productive System Example: Picking

Whoever comes into a large manufacturing or production shop floor will immediately realize the difficulty in introducing any kind of sensitive equipment to such an environment. By their very nature these environments are crowded with workers and/or robots, are noisy, mostly tidy but dirty, have very little wasted space (no room for extras), and are a scene of endless activity.

Given the requirement to provide a value-adding augmented reality application, the identification of a suitable workplace is very hard. AR technology at this stage of maturity is far from being robust enough to be applied to the whole manufacturing process. Together with internal and external specialists (ar-solutions.de, shared-reality.com) we have identified some application scenarios where AR could be applied successfully and could gain a reasonable return on investment.

In two German car manufacturing plants we were investigating applications for the use of AR technology with the potential to provide the benefits mentioned above. The working process of "picking", present at all assembly line manufacturing locations, was chosen as an initial test case for the widespread use of AR.

Picking in this case refers to the manufacturing process where an employee picks car parts out of storage according to a sequentially numbered list of parts written on paper, puts these parts into a cart, brings the cart to the next process location for later just-in-time assembly, and confirms this action on the paper list.

The main shortcomings of this procedure are: (1) The list of items to pick is locally separated from the storage location to be picked from: this results in unnecessary travel between the cart and the storage shelf, (2) the confirmation of picked parts is done on paper and therefore error-prone, and (3) incorrectly reading the list (e.g. reading the wrong row) can also lead to errors.
There are two main technologies which attempt to address these issues: (1) A so called “pick-by-light” system, where lamps on the storage shelf indicate which part to pick next (including a confirmation button): this technology is not applicable in our scenario because the system has to be reinstalled every time the storage arrangement is changed according to new assembly line needs. (2) A “pick-by-voice” system instructs the worker using audible instructions via a headset. Confirmation is also done using voice commands. This system has not been accepted by a majority of workers for ergonomic reasons.
This task however looks like a promising candidate for the use of AR. The paper list can be transformed into electronic information brought to the worker on a head-worn display, and confirmation can be done electronically enabling greater integration into the entire logistic process. This approach is presented here.
A further motivating factor in selecting this task is that, if one can successfully introduce AR supported picking into a given manufacturing environment, (1) the resulting system can easily be modified and deployed into almost any environment where picking takes place (not limited to car manufacturing, but also in dispatch and other fields), and (2) that the proof-of-concept of AR in picking will serve as an enabler for the introduction of AR into other processes e.g. in assembly or servicing.
After conducting a comprehensive requirement analysis (not presented here for reasons of brevity) together with our supplier experts (ar-solutions.de and shared-reality.com) we have implemented the entire introduction process in an industrial case study. This was also conducted in close partnership with our customers and end-users with extended periods spent on site.
Here we focus on the process of data delivery and handling, the technology chosen, and the integration of the system into the existing working processes.

Data delivery

The logistics of a just-in-time assembly line is very complex and has to be robust and failure-free. The process we found at the car manufacturing plant was highly optimized and, with regard to the electronic data provision, without a single error in seven years! Any intervention in this process was going to be considered cautiously for good reason. Therefore “non-invasive” data integration was the only option.
For picking, the existing process can be described briefly as follows: A control system governed by the pace of the assembly line selects, compiles, and provides a “selective assembly task”. This is sent to the appropriate printer within the picking storage area. Multiple tasks are put onto one sheet of paper that is retrieved from the printer by the worker. After the completion of each picking task, confirmation that this task has been completed is made by writing a checkmark on the sheet. All sheets from a shift are collected and checked.

In the case where clarification is required and for specialized assembly tasks, additional information is needed in form of drawings or textual descriptions. This is rarely used in the picking process, but is often used in assembly processes on the production line.
After much consideration, a data delivery solution was developed where a virtual printer was implemented and controlled in exactly the same way as the real printer. With this approach we (1) ensured that the actual current data are sent and (2) enables paper and AR to be used in parallel, which is needed for the initial introduction phase and doubles as a fallback in the case of malfunction of the AR system.

We implemented a tailored software on a dedicated PC networked to the production system, which presents itself to the rest of the system as a printer. Figure 8 shows an example of the user interface of an AR client. The information displayed is reduced to necessary information only, with options for additional requests. The interface is operated by buttons only and (in this example) makes use of different colors and font sizes to ensure effective information delivery.

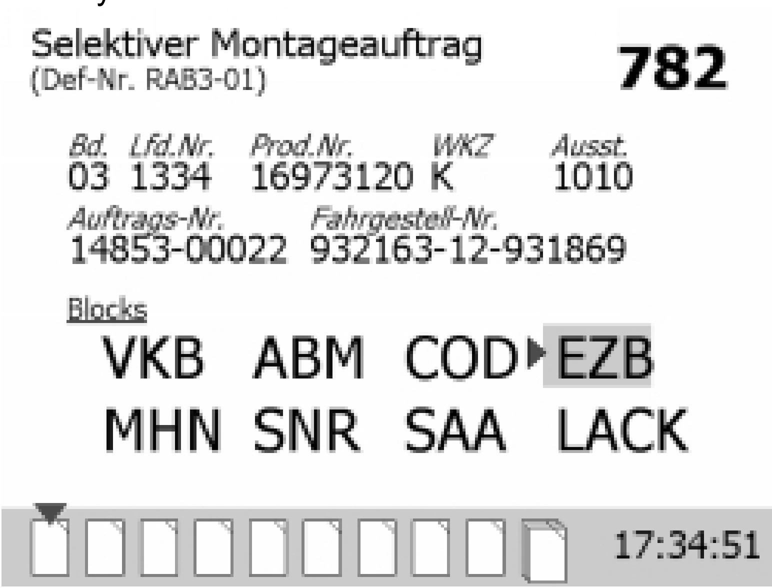

Figure 8. Example of display content

At this stage of the project we haven't done any optimization of the sequence in which data is presented. The data is presented in the same temporal and content order as on the paper. The only difference is the layout and amount of information shown at once. In a later step it might be advisable to optimize the sequence according to part type, location in the storage facility or even on a user's individual preferences.

Wearable Technology

If one wants to support a given workflow with new technology, the technology itself should really be of help and must not disturb or distract the attention of the user. In our case, the AR technology and interface should be as unobtrusive as possible and should not require massive instrumentation of the environment or worker.

We considered various display and computer technologies for use within our scenario, like tracked video-see-through head-mounted displays, head-mounted or environment mounted projectors, and displays on the cart or within the storage environment. Eventually two systems remained worth considering, the first being a combination of a MicroOptical display unit and a Personal Digital Assistant – PDA and the second a Microvision Nomad Expert Technician System consisting of a head-worn display unit connected to a Nomad wearable computer (see figure 9).
Both systems include integrated wireless LAN (WLAN), work with lightweight head-worn displays, the computer units can be worn on a belt and are battery-operated.

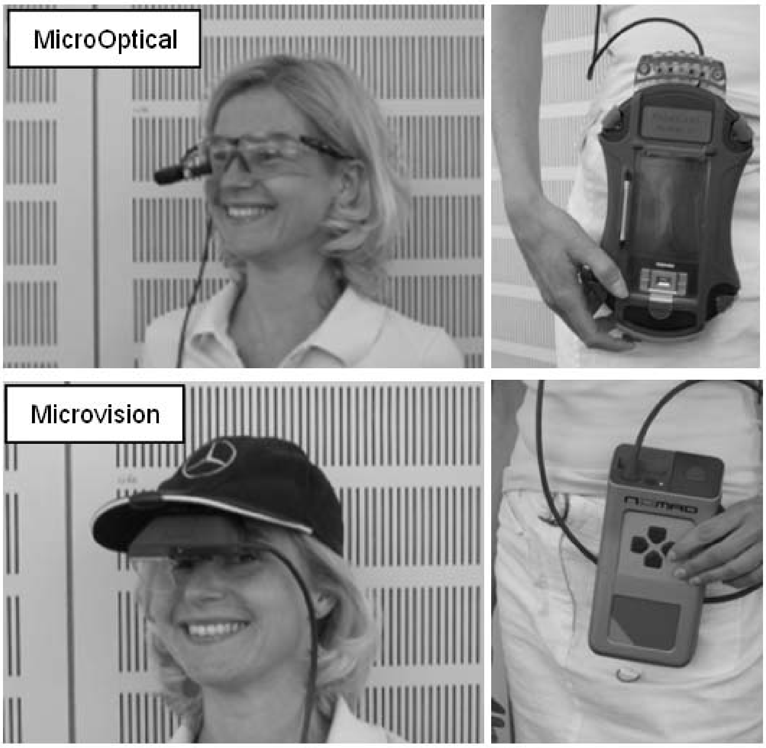

Figure 9. Displays and wearable computer units of technologies chosen.

The MicroOptical display unit was attached to standard safety glasses. Workers are obliged to wear these glasses while working. The PDA was integrated into an industrial housing with customized buttons for operating the unit mounted and interfaced to the PDA. A high capacity battery was used instead of the standard one.
The Microvision display unit was attached to a baseball cap (see figure 9 bottom left).
The pros and cons of each system can be summarized as follows:
Both systems were robust enough to be suitable for the picking task environment. The housings and components used already do, or will soon, comply with industry requirements for the near future. Although not extensively tested yet, both computer units as well as the display units were acceptably comfortable to wear, though we recognize there is room for improvement.
The main issue is the display technology: the MicroOptical system blocks parts of the user's sight. Even though this is only a small portion of the entire field of view, it is disturbing and concerns the customers. The Microvision

system allows for optical see-through and therefore blocks only those parts of the environment where the actual information is displayed. Unfortunately a psychological aspect comes into play with the Microvision system. Because the image is provided by applying a laser beam to the retina of the user an acceptance barrier has to be broken first before one can introduce the display. To be worn for a full working day (a shift) a wearable AR system has to operate continuously for about eight hours. Because of the high-capacity battery used in the MicroOptical/PDA system this can be achieved easily. The Microvision system on the other hand, when operated together with the WLAN, has to be recharged after less than 4 hours. If no extra battery option is available, more than one system per worker and shift has to be provided including a transparent, continuous, and seamless information provision / hand-over.
The user interface has to be robust, easy-to-use, and must not require fine motor-movements to control, like mouse cursor movements. For this reason the use of a button-only interface is advisable. This can be implemented with both systems. The lack of colors with the Microvision system can be substituted with a careful interface design.

Process integration

The readiness to invest into Augmented Reality technology for a customer presupposes the provision of return on investment (ROI) estimates by the AR technologists. In our case the customer was already given a report by an external supplier on the ROI of AR introduction into certain assembly processes. Together with the customer experts and our suppliers (ar-solutions.de and TU Munich) we double-checked this report and computed new ROI numbers for the picking task as it had not been considered in the report. This provided the base for our presentation to the management and eventually led to the financial and organizational support for this implementation study. Without any ROI figures it would have been very difficult to start the project on a serious level.
A necessary next step was to establish a close working relationship with the customers. We had to identify their current work processes, their needs, expectations, and ascertain their attitudes towards new technologies in general and AR in particular. We presented pilot prototype examples to potential users, union representatives, group leaders, and occupational health and safety experts (including the company physician). We found the various customer groups receptive to the new technology and willingly to support the introductory process and its eventual deployment. Later on an informal user interview study was carried out to get an idea of the potential level of acceptance within the worker community and it was actually very high.
Last but not least, we established an ongoing communication schedule with the technicians and IT experts within the enterprise whose support was critical to the AR project in providing data and infrastructure assistance.

Compared to state-of-the-art Augmented Reality research projects our approach is a very humble one from a technological and invention point of view:

- We are using commercially off-the-shelf components with little modification.

- We display two-dimensional information only.
- This overlaid information consists of text and some graphics only.
- The user is neither located, nor tracked, nor registered within the environment.
- The tangible user interface is reduced to button-clicks.
- The task to be supported is very simple by nature.
- All information for task completion is available.

It becomes apparent that the focus of efforts with a productive system compared to demonstration and prototype systems shifts from the introduction of new and unique solutions to process and data integration and robustness and reliability. We have neither developed new hardware nor have we invented new algorithms. The main challenge was the analysis of the requirements and the implementation of a seamless integrated solution.

5. Conclusion

We have briefly introduced augmented reality projects applied in the automotive and aerospace industries. As shown above there are many technical and organizational issues to be resolved before one can apply AR in the field. Besides the application-specific issues addressed, some general guidelines can already be drawn from the experience we have gained. Even those may not represent empirical evidence; we think some humble suggestions can be made here that have value for anyone who wants to apply AR in an industrial context.

Data integration

Firstly, the effort required to incorporate real-world data into the AR application are often seriously underestimated. Most demonstration scenarios work pretty well with (manually) pre-configured and specially prepared data sets. When it comes to the first real data trial, however, the systems mostly tend to fail. This is usually either because of the quantity of data needed, or the complexity and historic diversity of the data. One could probably argue that the data delivery and preparation falls outside the realm of AR research, but nobody else better understands the data interface than the team of end-users and AR researchers involved in the project. The early consideration of real-world data sets is crucial for the successful final deployment of the system.

If the existing data cannot be used right away, a dedicated workflow and tools (especially authoring tools) need to be developed for successful process integration.

Acceptance

AR technology and research has not yet reached a level of maturity that allows for a widespread deployment “from scratch”. The initial application fields need to be identified very carefully with key persons in innovator roles. These persons should work together with the researcher as close as possible, should know the application field very well, and should be widely accepted among their colleagues to serve as a point of multiplication for later dissemination. If one cannot find such a person who fully accepts the approach and is willing and able to drive it to success, the entire project will probably fail. Furthermore, the integration of many parties in the early process

of the project (managers, company physician, union representatives etc.) is laborious but worthwhile. Additionally, usability studies with representative subjects should be a part of every application project.
Finally, if one has the opportunity to choose between different application scenarios, the preference should be given to single-user, single-location, and single-task settings. There is a far greater chance of success if your AR system is setup in an “island” environment compared with, for example, trying to equip hundreds of workers with wearable AR systems.

Simplicity

Albert Einstein once said: “Keep it simple, but not simpler!” This is very true for industrial AR projects. From the researcher’s point of view the best solution found might not be the one with the highest level of originality or novelty, but imagine if the users realize later on that there was a simpler, more elegant solution for their problem. The disappointment will probably put an end to future cooperation. It is advisable therefore to provide a simple, but accepted solution first and to build on it for advanced versions at a later time. The maturity of AR display and tracking technology in particular seldom allows for the use of the most advanced and most recent systems available. One has to consider all alternatives available. Choosing the most accepted and robust one is always better than offering the latest “bleeding-edge” technology.

Added Value

At the beginning of a planned project, consideration of factors like cost, quality, time, and knowledge obtainment helps and often enables the project to get started. Even if the figures are “educated guesses”, estimates of the value added and sometimes even a return on investment appraisal are widely expected. Indeed, this is not the core competence of an AR researcher, but it is to be expected that the researcher will be concerned with these issues. Preferably, one can find experts in the field of industrial economics to provide appropriate data or estimates.

Demonstrators and Prototypes

As shown in the first part of this chapter, a huge number of convincing demonstration and prototype systems are needed before a productive system can be developed and introduced. From our experience, these systems should avoid to “pretend” to be productive systems. Rather the knowledge gained with these systems will probably lead to much better and productive solutions.
All types of applications are actually needed for successful innovation in the field of industrial augmented reality.

In a mid-term perspective, augmented reality is on its way to become a productive tool in industry. The spectrum of application fields is very wide and early applications of the technology have already demonstrated its value. A comprehensive, multi-disciplinary approach to future research and development conducted in partnership with potential users will bring about the increased use of AR.

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