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Developing Killer Apps for Industrial Augmented Reality

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Although augmented reality first emerged with Ivan Sutherland's experiments in the 1960s, AR didn't gain real footing as a technical field until the early 1990s.[1] For example, that's when David Mizell developed the first industrial AR application with his colleagues at Boeing.[2] By the end of that decade, interest in AR had grown considerably—motivated in the US mostly by military considerations, in Japan by art and entertainment, and in Europe by industrial applications.

A series of publications in newly organized augmented and mixed reality workshops and symposia documented these trends. Because governments and the entertainment industry funded much of the academic research, many publications focused on topics that interested these groups. This meant that publications covering AR's industrial applications were largely lacking. The largest industrial AR (IAR) consortium was funded by Germany's Federal Ministry of Education and Research organization, which supported the Augmented Reality for Development, Production, and Servicing (known by the German acronym ARVIKA). As a consortium that included numerous industrial partners, ARVIKA's emergence is an important milestone in establishing IAR's importance and attracting industries—in particular, the German automobile industry—to its applications.

Even though this consortium produced numerous patents, only a handful of scientific publications appeared in peer-reviewed journals and conference proceedings. (A final report presenting the summary of results obtained by each partner is written in German and might be translated into English in the near future.[3]) ARVIKA's main achievement was to incite industry to form R&D groups that would study industrial applications of AR and build prototype systems. Research groups from other countries such as Sweden, Australia, Japan, and the US, among other countries, have also presented some IAR-related research work (see references in http://wwwnavab.in.tum.de/CGA).

The European community also funded several projects—including the Service and Training through Augmented Reality (STAR) program—to encourage IAR research and development. In the next few years, we will see whether the IAR community can provide satisfactory end-to-end solutions and whether industry will adopt and commercialize these solutions. Each industrial process imposes its own peculiar requirements. This creates the need for specialized technical solutions, which in turn poses new sets of challenges. Because most industries must concern themselves with at least some of these industrial procedures, let's consider design, commissioning, manufacturing, quality control, training, monitoring and control, and service and maintenance.

Design

Although AR developers have proposed alternate advanced solutions for design to those developed by virtual reality researchers, they have not yet proven AR's superiority in these fields. Design often requires high-quality, real-time rendering; any minor lag or misalignment dramatically affects the artistic perception of design. AR's cost-cutting solutions offer advantages—such as when the new design needs to be perceived within an existing environment—but AR still needs to improve its quality and efficiency compared to VR or augmented virtuality.

Commissioning

In practice, designers and building crews rarely come from the same engineering company. Checking an as-built installation's conformity to the original design is crucial. The reason is not only for financial advantages related to delivery, payment, and quality control, but also for allowing the creation of as-built documentation before an installation's productive lifetime begins. Even though I will discuss later in this article R&D that has direct applications in commissioning, we have not yet seen a direct implementation in industry.

Manufacturing

In the early 1990s, Boeing's IAR wire bundle assembly project aimed to make obsolete the use of prefabricated guidance boards for wiring. As the first project to introduce the use of optical see-through head-mounted displays (HMDs) and wearable computers, this project produced a series of scientific publications and generated considerable enthusiasm for the community. Unfortunately, it did not garner the necessary acceptance from either its final users or their higher-level managers.

In the ARVIKA project, similar solutions emerged for

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Head-Mounted Displays for Industrial Augmented Reality

Industrial augmented-reality (IAR) solutions must surmount two major bottlenecks before they can be further developed and commercialized: They must provide online calibration and evaluation of see-through displays and real-time precise tracking of users and displays. Options for augmenting a user's view of the surrounding world include

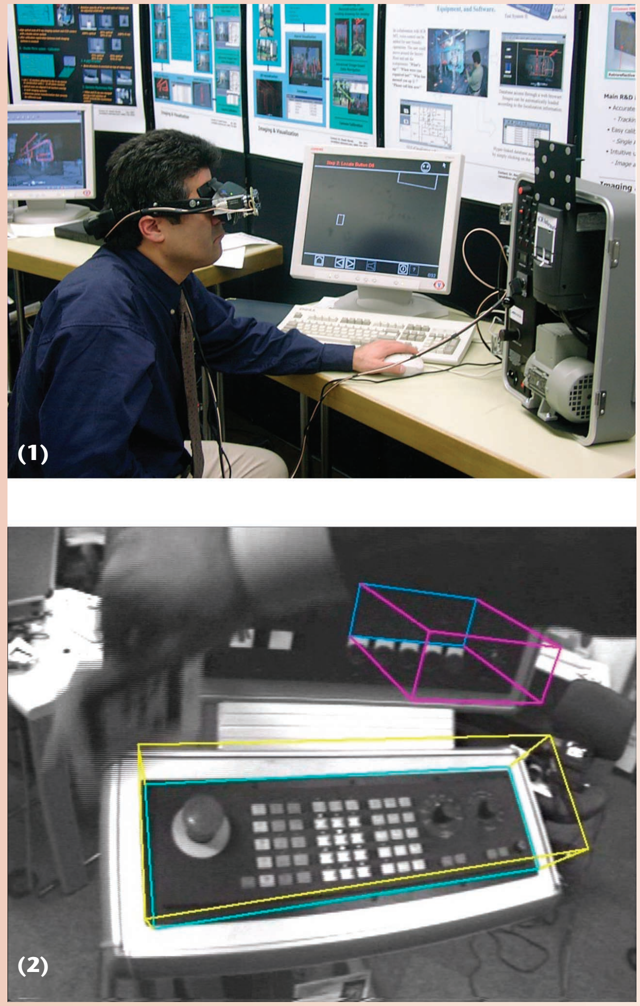
- projecting virtual components onto the real world,
- observing the world through video cameras and integrating virtual components into a camera view,
- projecting virtual components onto the user's retina, and
- observing the real world through a semitransparent display for visualizing the virtual components.

Other than for design scenarios, only the last two options are commonly acceptable in IAR applications. These are the only types of displays that offer an essentially unhindered view of the real world that also provide safety and security.

American Honda Motors recently announced its distribution of nomad virtual retinal displays (VRDs) from Microvision to Honda and Acura dealers. The system uses wireless communication and a belt-worn computer system to overlay diagnostics and repair instructions onto the view of repair technicians. ARVIKA also considers optical see-through and VRDs as the HMDs of choice for industrial applications. Almost all prototype systems ARVIKA has developed use video see-through systems, mainly because of the open issues in online calibration, tracking, and evaluation of optical see-through displays.

A major challenge here is achieving offline and online calibration of see-through displays relative to the user's view of the environment. The difficulty arises because augmentation occurs only on the user's retina, and its effect on the final interaction with industrial environments also depends on the user's dexterity and hand–eye coordination. Additionally, for routine industrial use, the user needs to easily recalibrate such a system and frequently evaluate the final augmentation result's accuracy.

At Siemens Corporate Research, we proposed a set of original solutions to these problems, starting with the introduction of the single-point active alignment method in October of 2000.[1] As Figure A shows, a series of improved calibration methods by original authors and other researchers



A (1) Siemens Corporate Research's first prototype of an optical see-through HMD system for factory automation. (2) If feature-based tracking and localization results are reliable and satisfactory after the initial learning and training phase, the system will let users remove markers.

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wire bundle assembly in airplane manufacturing, but these results have stalled at the prototype level, not yet finding regular use in production units. The only solution for manufacturing that has enjoyed early user acceptance is the so-called AR welding gun, developed by the Technical University of Munich and BMW within the ARVIKA consortium. This system combines the advantages of external tracking systems with ubiquitous displays to let workers weld the body of early automobile prototypes. Although the system does not use image augmentation or HMDs, it does provide a particular solution to a well-defined, practical problem.[3]

See the "Head-Mounted Displays for Industrial Augmented Reality" sidebar for further discussion of manufacturing applications.

Quality control

Although ARVIKA has also suggested IAR techniques for quality control, technologies such as laser- or camera-based photogrammetry offer valid alternatives.[3] For example, Volkswagen researchers have built a prototype system for superimposing simulated damages onto a crashed car. The question remains whether this system is better than precise 3D reconstruction of the damaged surface by laser-based systems that exactly compare results to the simulated model.

Training

IAR's training applications offer the advantages of VR systems without immersing users into a virtual space. This approach lets the training system consider many

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have produced practical solutions for offline calibration of optical see-through HMDs. We then introduced an evaluation concept using a secondary sensor that measures the personalized effective accuracy of see-through augmentation systems. This development also lets us quantify the overall augmentation error for each individual user and account for it in improved calibration.

Several tracking systems or hybrid solutions are available for tracking a user's HMD. For industrial applications, using a camera attached to optical see-through HMDs is especially useful for calibration, tracking, and localization. A major advantage lies in using the attached camera for communicating with remote experts. The images could also help the augmentation system choose the best color and visualization mode for virtual objects as a function of the background intensity. The attached camera for tracking and localization could use predefined markers or natural features to recover its position and orientation.

Existing solutions rely primarily on visual markers, even though covering an environment with visual markers is cumbersome. Consequently, interest is turning to feature-based tracking. To my knowledge, no computer vision or photogrammetry software currently available can guarantee real-time feature-based tracking and localization in all lighting conditions and in the presence of partial occlusion.

To develop an HMD-based solution in the near future, we must quantify the system's accuracy and guarantee its minimum performance. The solution our group proposes relies on an initial training process, during which feature-based tracking and localization results are systematically compared to ground truth obtained using markers or additional external sensors. If results are robust and accurate, we could switch to a markerless solution, as shown in Figure A. Our first version produced promising results, but there are many challenges to surmount before general solutions can come forward that will easily integrate into the final optical see-through-based applications.[2]

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issues related to safety and security that are specific to particular working environments. Currently, such solutions exist only as research prototypes for in-house use; they are not yet as close to the market as some medical AR and VR training systems.

Monitoring and control

Technologies such as computer-aided design, VR, and advanced visualization have made their way into design and development procedures for a great number of industrial sites. New installations often come online based on models that are fully designed, visualized, and evaluated within virtual environments. These virtual models often connect to sophisticated databases, which store and make available the manufacturing information, part specifications, and even functional characteristics of components.

Unfortunately, in an absolute majority of cases, this valuable source of information is not used during the industrial installation's lifetime—nor is it maintained and updated. Connecting these rich virtual models to the physical components in the factory and relating them to the automation, monitoring, and control software used day in and day out would be of immeasurable value. Imagine walking around a factory and accessing any inventory or functional data just by looking at a component or asking a sensor about its status.

However, the solutions proposed so far are often not scalable, usually dealing with local identification and tracking, and not addressing the main issue of connection to existing databases. The ultimate solution of integrating virtual models and their associated monitoring and control data into a mobile IAR solution is an ambitious goal. I have been working toward this goal since the late 1990s, which led me to create an IAR group at Siemens Corporate Research (SCR) in 1998. We worked closely with Framatome ANP to provide augmented images of plants with intelligent 3D models that give mobile workers easy access to engineering, monitoring, and maintenance data.

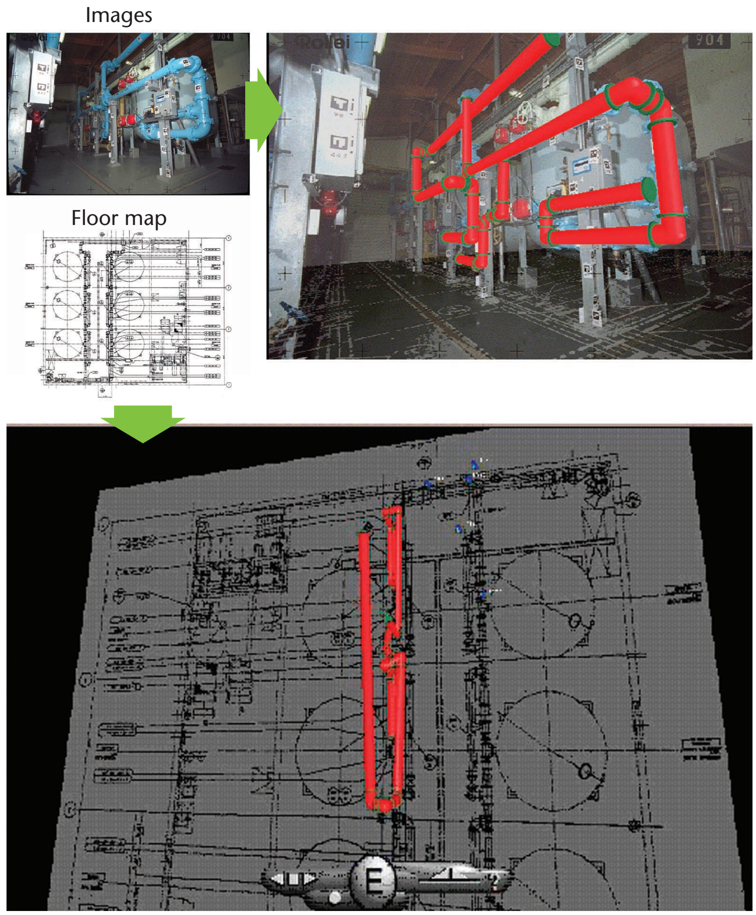
The system Siemens and Framatome have developed aims at integrating 3D models, industrial drawings, factory images, AR visualization, computer-assisted tracking and localization, wireless communication and data access, and speech-based interaction to provide end-to-end solutions that empower wireless workers (see http://wwwnavab.in.tum.de/Chair/TechTV). SCR's pilot system enables users equipped with a mobile computer to move about their environment, while providing them with location-based information. Users interact with the system either through a standard pen- or mouse-based interface or a speech-enabled one.[4] Wireless communication lets a mobile computer retrieve information either from real-time automation and monitoring software or a factory engineering database.

Building on a long history of related work, we originally created CyliCon—an IAR software solution developed at SCR—for as-built reconstruction of industrial pipelines (see Figure 1). The software's image augmentation functionality reduces the need for complete, exhaustive reconstruction of an environment. AR lets users reconstruct virtual models of their area of interest and visualize the models within the static views of a real scene. Because our industrial customers stressed the importance of industrial drawings, we integrated these documents into CyliCon, which gave birth to a new set of augmented documents called *coregistered orthographic and perspective* images.[5,6] COP images let us design new calibration and 3D reconstruction algorithms, reducing the need for calibration markers.[7,8]

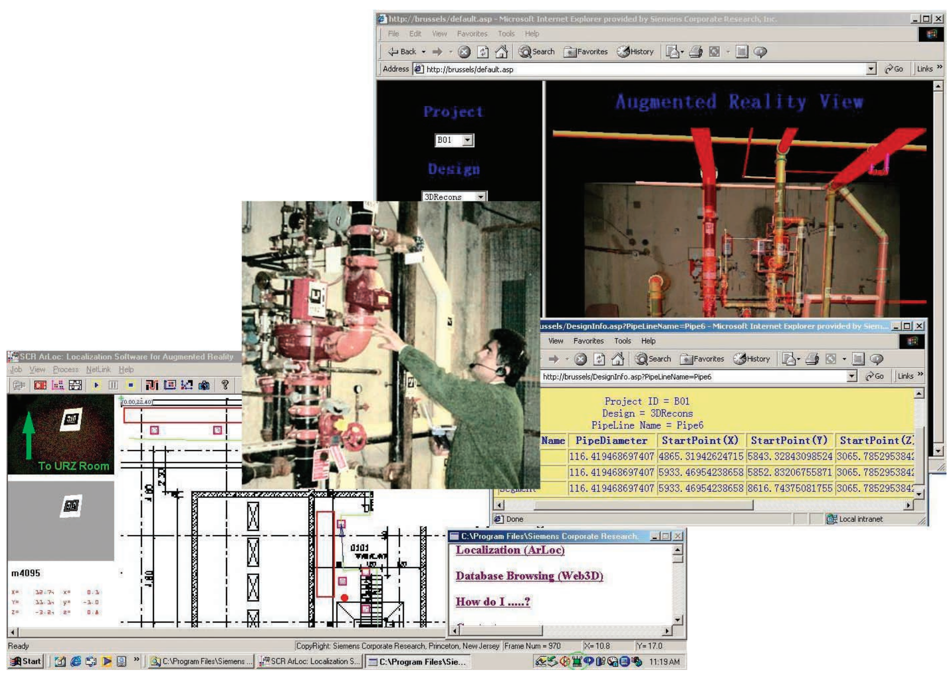
For locating users in large industrial environments, we built marker-based tracking and localization solutions. By combining this solution with CyliCon and COP images, we could propose new solutions for mobile AR visualization and data access, as Figure 2 demonstrates.

The latest projects defined jointly by Framatome and SCR let users take interactive images and relate them to previously acquired 3D data. The first project uses markers to automatically calibrate cameras and overlay the 3D data on acquired images. The second project—implemented at Siemens CT-PP4 Division—uses industrial drawings to interactively calibrate the camera for augmentation. In both cases, interactive overlay lets mobile users click on images and directly access plant databases.

CyliCon is a promising application that can encourage traditional industries to use 3D virtual data and digital images. Because this approach integrates the factory database through previously acquired intelligent 3D models and provides user localization based on existing industrial drawings and floor plans, it is both cost-effective and scalable beyond simple prototype systems.



1 **CyliCon not only provides as-built reconstruction functionality, but also augmented-reality visualization of images, drawings, and virtual models.**



2 **Mobile augmented reality lets industrial users easily access data through augmented views of the real world.**

Service and maintenance

Although the main issue in service and maintenance also involves accessing databases, here I'll consider other applications in industries where service and maintenance is provided off-site on delivered products—for example, the automotive industry.

Numerous research groups are working on these types of applications, but they have produced only demonstration prototypes. These approaches range from Columbia University's AR prototype for laser printer maintenance procedures and Dynamic AR labeling of engine model parts in the early and mid-1990s to the most recent ARVIKA demos for car engine repair.[3,9,10] The prototypes often involve overkill for the application at hand, are neither easy nor practical to set up, and don't scale well to cover large numbers of parts and components.

The common problem here is that such IAR solutions are not well integrated into existing service and maintenance workflows. Still, industry greatly appreciates the use of mobile handheld or wearable computers that can easily interface with existing systems. For example, these devices can act as system applications and product front ends. They let on-site maintenance crews send remote experts system parameters and provide the mobile system with diagnostics information and guidance.

Current maintenance procedures capitalize on existing wireless communication methods to check spare parts and allow real-time remote task management and optimized dispatching of maintenance personnel. IAR solutions must come forward as additional user interface components, increasing efficiency wherever possible. For maintaining large industrial sites, the monitoring and control solution I discussed earlier could also apply.

For maintaining and repairing automobiles and other industrial or consumer products, intelligent maintenance editing software must be developed that can then be adopted for use in AR technology. Current manuals often lack necessary information that would enable R&D groups to provide general and scalable AR solutions.

Conclusions

A killer AR application would provide better solutions than traditional approaches, win favor with a large number of customers, and create major financial benefits for industry. Researchers should remember that end-to-end IAR solutions can be commercialized only when they provide the following advantages:

- Reliable. They should provide robust and reproducible solutions, providing a high measure of accuracy and possible fall-back solutions.
- User friendly. Users must find them safe and easy to set up, learn, use, and customize.
- Scalable beyond simple prototypes. Plant owners and operators and manufacturers need to easily reproduce and distribute them in large numbers.

Currently, the IAR research community is emerging from the first phase of defining use cases and building simple prototypes. For designing and building killer apps, AR researchers now need to take several related steps. They need to deeply understand each industrial process and its requirements, study its end users and their levels of expertise and current environments, and consider all aspects of the problem in setting up multidisciplinary research projects. Finally, they need to consider marketing and commercialization aspects of possible AR solutions as they define the right academic and industrial partnerships and develop clear dissemination plans. Much of this is already happening as industry prepares to modify its current workflow, adopt the new technology, and absorb advanced IAR solutions. ■

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