ARVIKA Augmented Reality for Development, Production, and Service

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Summary

Augmented reality is a novel approach to the interaction between humans and machines in which information is displayed in the field of vision of the human operator, say, using an eyeglass display, and therefore augments the reality perceived. This is context-sensitive, which means that it depends on the object being viewed, which might be a component, a tool, a machine, or the operator's location. The real field of vision of the skilled worker, technician, or development engineer is thus enhanced with information important to them at that time. The coordinating project ARVIKA backed by the Federal Ministry of Education and Research is developing this technology in the applications development, production, and service in the automotive and aerospace industries, for power plant and process plants, and for machine-tools and production machines. This technology offers mid-sized businesses special prospects because they can become more flexible and efficient due to improved competence in diagnostics and maintenance and therefore stronger in the face of global competition.

Keywords

Augmented Reality, Wearable Computing, Situation-Oriented Action, Applications Automotive, Aerospace, Power Generation, Production Machines

1. MOTIVATION, OBJECTIVE, AND PROCEDURE

Our coordinating project ARVIKA, sponsored by the German Federal Ministry of Education and Research (BMBF) uses augmented reality (AR) technologies to research and implement a user-oriented and application-driven support for working procedures in the development, production, and servicing of complex technical products and systems. The visual overlaying of computer-generated virtual objects over real objects enabled by augmented reality technology permits situation-oriented action in real working environments.

The project ideas are being implemented in applications relevant to German industry, such as automobile manufacture and aircraft construction, mechanical engineering and system development. This technology offers special prospects to mid-sized businesses who can strengthen their position in global competition because they can become more flexible and efficient due to improved competence in diagnostics and maintenance.

Augmented reality (Fig. 1) is a novel approach to the interaction between humans and machines. For example, information is displayed in the field of vision of the human operator, say, using an eyeglass display. This is context-sensitive, which means that it depends on the object being viewed, which might be a component or a mounting environment. The real field of vision of the technician is thus enhanced with assembly instructions and other important information. In this case, augmented reality both replaces the conventional instruction manual and provides additional current process-related information, such as pressure, temperature, and speed. In addition to this situation-oriented interaction, wearable computers enable AR to be applied in areas where mobility is very important and where data from processes, measurements, and simulations are needed to support the task at hand.

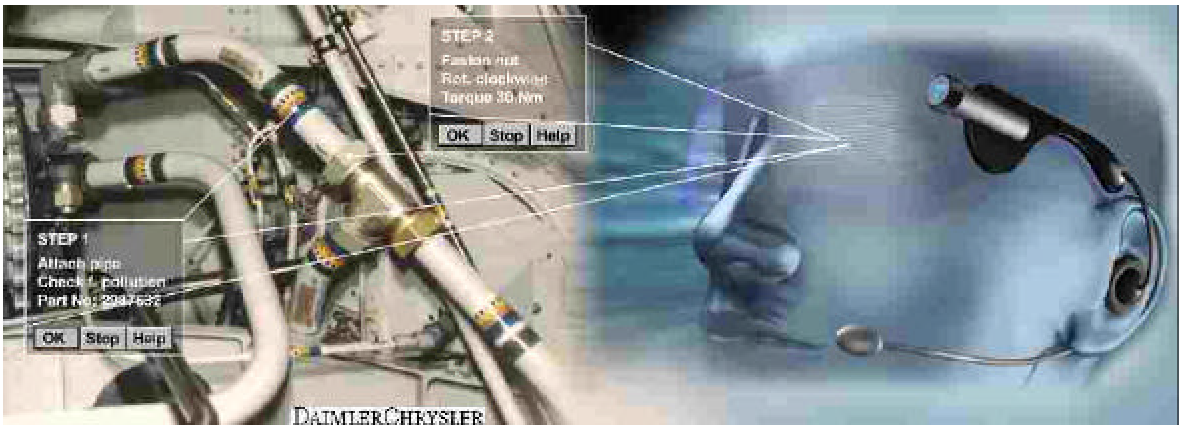

Fig. 1: Example of augmented reality, courtesy of: DASA Airbus

The main application-related topics (Fig. 2) of ARVIKA have the aim of testing augmented reality in the *development*, *production*, and *servicing* of the products being used, or the servicing of the machines and systems required for production. The scheduled scope of the project is concentrating on the following areas: for development on automobiles and aircraft equipment, for production on automobile and aircraft assembly, and for service on power plant and process plant engineering and the production machines required for production. This covers the major application areas of AR, avoids duplicate developments, and enables thorough application-oriented verification of this novel technique.

These main topics are incorporated in a *user-centered system design* that is to be found in all project phases and is based on methods of ergonomic science.

All applications in this research are based on *augmented reality base technologies* supporting both the high-end/power applications in the development process and the low-end activity of the skilled worker using belt-worn equipment in real production and service environments. This is achieved with an open platform that allows for different performance grades and especially true wearability. This project is geared toward market-oriented support for production, manufacturing, and service-oriented information and communication technologies by mobile augmented reality systems to be used by skilled workers, technicians, and engineers.

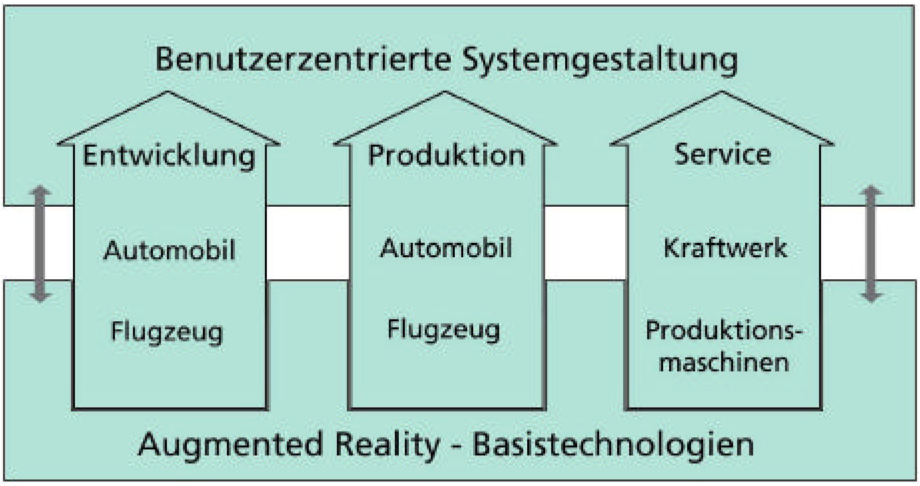

Fig. 2: Main topics

2. USER-CENTERED SYSTEM CONFIGURATION

User-centered system configuration is achieved in four steps (Fig. 3)

- Determining user and customer requirements of AR systems
- Agreeing the requirements with project managers or marketing experts to take account of technological and economic interests
- Compiling the specification for the AR systems in cooperation with systems analysts and software engineers
- Measuring improvements in the applications from the ergonomic and economic points of view.

The work processes along the value creation chain are identified (scenario-based procedure) and suitable applications are prioritized. These work processes are modeled in activity diagrams and potential for user and task oriented improvement with AR base technologies is determined. The AR ideas obtained are implemented on examples in the form of software mockups to illustrate the target scenarios obtained to the future users more clearly. This ensures that the knowledge gained can be implemented completely and without contradictions.

As for evaluation of the AR systems, usability testing is conducted to examine ergonomic aspects of hardware and software, the time-cost and quality effects of the use of AR in the work process and the benefit of a global AR-assisted presence is quantified. Finally, various components available on the market, such as head-worn see-through displays or interaction devices (voice input, wrist-worn keyboard, etc.) are evaluated for suitability for use with AR in development, production, and service so that a well-founded "make-or-buy decision" can be taken.

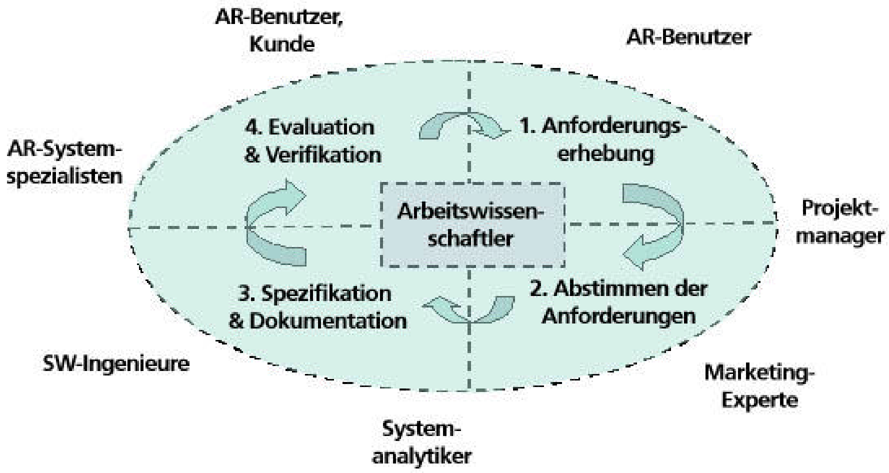

Fig. 3: User-centered system configuration

3. APPLICATIONS

The main topics of ARVIKA relating to applications are the testing of augmented reality in development, production, and servicing of the product in use or the machines and systems required for service and production. To ensure the AR is also of benefit in extensive plants, scenarios are being tested in which service and maintenance in large plants, such as power plants, is supported.

3.1. Augmented reality in development

The development application is characterized by the partially virtual development environments of the development engineers in the automotive and aerospace industries. The use of augmented reality in the development and design of products necessitates a high technical and technological effort although only a low unit quantity is to be expected. Because the costs of development of the systems in question are very high (1 day of development typically costs 0.5 million euros/dollars), even apparently expensive technologies are of great benefit because they can decisively reduce development times and considerably boost quality.

Three scenarios for the development or product creation process are being discussed in ARVIKA:

- Ergonomic layout design and flow visualization of pilot's and passenger seats
- Verification of pressed components against the CAD data
- Comparison of the test and calculation in crash tests.

Development engineers can expect promising support with ergonomic layout design of aircraft cockpits by the overlaying of virtual layout elements over real cockpit mockups, for example, to optimize the combination of real and virtual instruments in the development phase. For flow visualization on aircraft seats, invisible data such as air flow will be made visible and evaluated in the real human/seat environment using augmented reality technologies. High-quality tracking with millimeter or pixel precision, a spatial volume of up to 28 m^3, and a hybrid rendering approach permitting virtual reality, 2D video, 3D real world depths, and 2D/3D text information are all AR system requirements. The future inclusion of various interaction techniques (e.g. gesturing), which must of course be useable intuitively, must be possible.

In a further scenario, the existing pressed component (e.g. a car's fender) is compared with the CAD geometry of the design data. This topological and geometric comparison is implemented using overlaying technology inherent to augmented reality and thus allows the test engineer to verify the component by information composition before building a physical prototype.

Comparison of test and calculation of the crash test scenario (Fig. 4) supports the calculation engineer in the field of structure simulation using AR techniques. By overlaying virtual and real components, fast comparison of the real and simulated vehicle is achieved before the test is conducted. After the crash test has been conducted, AR technology supports immediate comparison of the calculation results of the crashed vehicle. The data is mainly graphic information (finite element method grid) that is coupled to results such as stress, strain, internal energy, and can be supplemented with text information.

Vergleich Rechnung-Versuch am Beispiel Fahrzeug-Crash

Fig. 4: AR in development

All scenarios for use of augmented reality in the development process are characterized by the great demands for precise recording and location of components/contours, precise matching between virtuality and reality, and high display quality for fast identification of deviations.

3.2. Augmented reality in production

With augmented reality in production, ARVIKA is pursuing the objective of implementing situation-oriented overlaying of information in eyeglass displays using networked wearable computers for the skilled worker in the production and assembly process in the aerospace and automotive industry and of testing them in application situations.

3.2.1 Augmented reality in assembly optimization

The objective of AR in assembly optimization is to investigate the possibilities of optimization of assembly and final quality inspection (finish area) using augmented reality technologies and implementing them in way that is suitable for the application. The ways in which an AR application can be used are examined both in large batches and in job shop and small batch production. In that way, application fields that differ in complexity and frequency of recurrence are considered in respect of AR support.

The aim of assembly optimization in **large-batch production** is improvement of the overall process starting with development activities relevant to assembly through prototype construction to series production. The important elements of these phases are the development of the product to be assembled, initial planning of assembly, and concept verification on prototypes, and finally the learning phase, introduction into series production, and adjustment or optimization during series assembly. In the learning phase, AR support allows the assembly technician to call up relevant information context-sensitively with a direct reference to the objects to be assembled. At the same time, they have the opportunity to document and explain any deviations from the specification as input for improvements.

Assembly optimization for **job shop and small batch production** is illustrated by the assembly of a transmission. The transmission is assembled on an assembly fixture on a workbench. This target scenario mainly results from the background of production of complex products with variations. Here, the technician is not primarily supported with performing recurring assembly tasks but with managing the voluminous variation data over the entire assembly process.

The scenario augmented reality in the **finish area** of automotive production refers to the acceptance testing and programming of vehicle electronics during vehicle assembly. To implement individual testing of each vehicle, the tester is guided through the test using a dialog. For that purpose, the vehicle is identified before the individual dialog can begin. In addition to testing the vehicle, the tester must also configure the electronics and document the results of the test to provide a test certificate for the car at the end of the test. Using AR support, virtual stimulation of the vehicle electronics must be conducted that provokes the corresponding response on the vehicle in reality. At the same time a virtual target signal is displayed in the field of vision of the tester. The tester compares the real response of the car with the target value displayed by the augmented reality system.

3.2.2 AR in assembly of complex systems

The objective of AR in assembly of complex systems in the aircraft industry is optimization of the assembly process by embedding the AR support in the assembly processes and compatible connection to the IT system environment. Application scenarios for aircraft production, in this case the equipment assembly A340 and A3XX, especially electric cable routing and water piping are available for testing (see Fig. 1).

A generic AR process is being worked out and tested on the nose landing gear of the Eurofighter (Fig. 5). The assembly technician fetches the work schedule, incl. the virtual component information from the workshop job management and views the mounting compartment to locate the mounting location. After that, the real work environment is visited and identified using the virtual preliminary information, the real world acquired with reference points and synchronized with the virtual world, and tracking activated. For the assembly process, the assembly technician obtains an overlay of the real view with virtual text, graphic, and multimedia information.

Not only are assembly processes that provide potential for using AR systems examined, but also the influence of AR on the whole product life cycle is considered. Only this view of the process permits objective and economic appraisal of the potential of AR systems. The AR demonstrator is integrated into the existing DP system environment. In product data management of the manufacturing companies all data are provided digitally during the entire product life cycle. In the product planning and control systems of the plants, product information structured for the applications are converted into technological work sequences. These interfaces are examined to create the necessary preconditions for connection of AR systems. In particular, the provision of powerful 3D geometric data for visualization and realtime synchronization with the real world is necessary for AR systems.

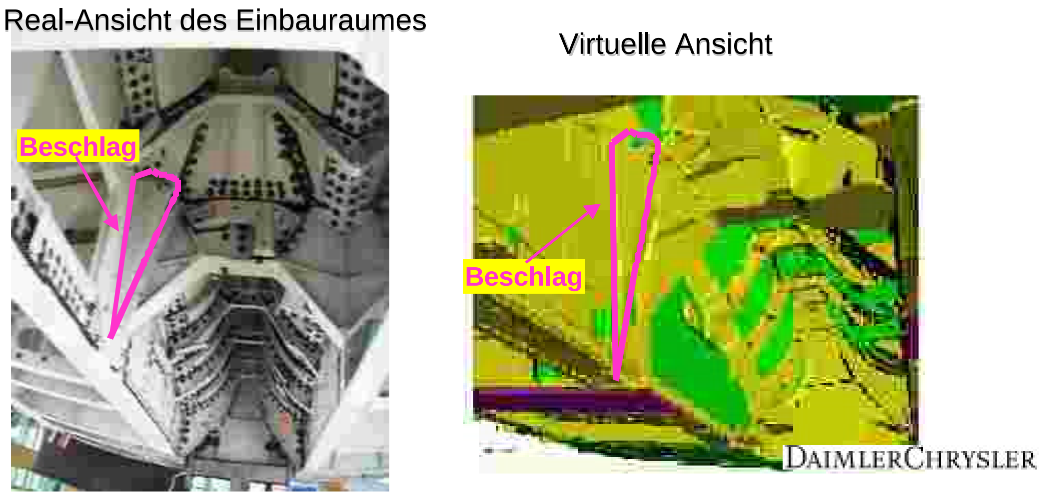

Fig. 5: Augmented reality with virtual models

All scenarios for application of augmented reality in production/assembly illustrate the new challenges to interactive modules in mobile use and demand the connection of the AR system to the specified production steps in such a way that the assembly technician/skilled worker is guided using the object-oriented information displayed.

3.3. Augmented reality in service

The objective of augmented reality in service is to support service work on plants and systems specifically in power plants and production machines even over large distances and in cooperation between specialists and the skilled worker in situ and to create a new quality of remote service by remote support of augmented reality. This last requirement is important to strengthen mid-sized businesses in global competition.

3.3.1 Power plants and process plants

For the application environment power plants and process plants, various tasks are being defined in the service and maintenance area and important criteria determined for task characterization (application/operating conditions, qualification,...). Using the example of several specific application scenarios (plant evaluation by inspection tour, fitting service, etc.), in "cognitive walkthroughs" with service technicians and plant evaluators in situ scenarios are worked out and visualized using software mockups. Design concept considerations concerning application and integration of IT technologies (calibration and overlaying of live plant mimics and virtual models) are being worked out.

Plant evaluation by inspection tour involves in situ tests (Fig. 6). The real situation is compared by overlaying targets, e.g. from isometric data, and any deviations found are identified, evaluated, and recorded. Parallel research and development projects from the area of proximity photogrammetry are taken into account to support orientation or tracking.

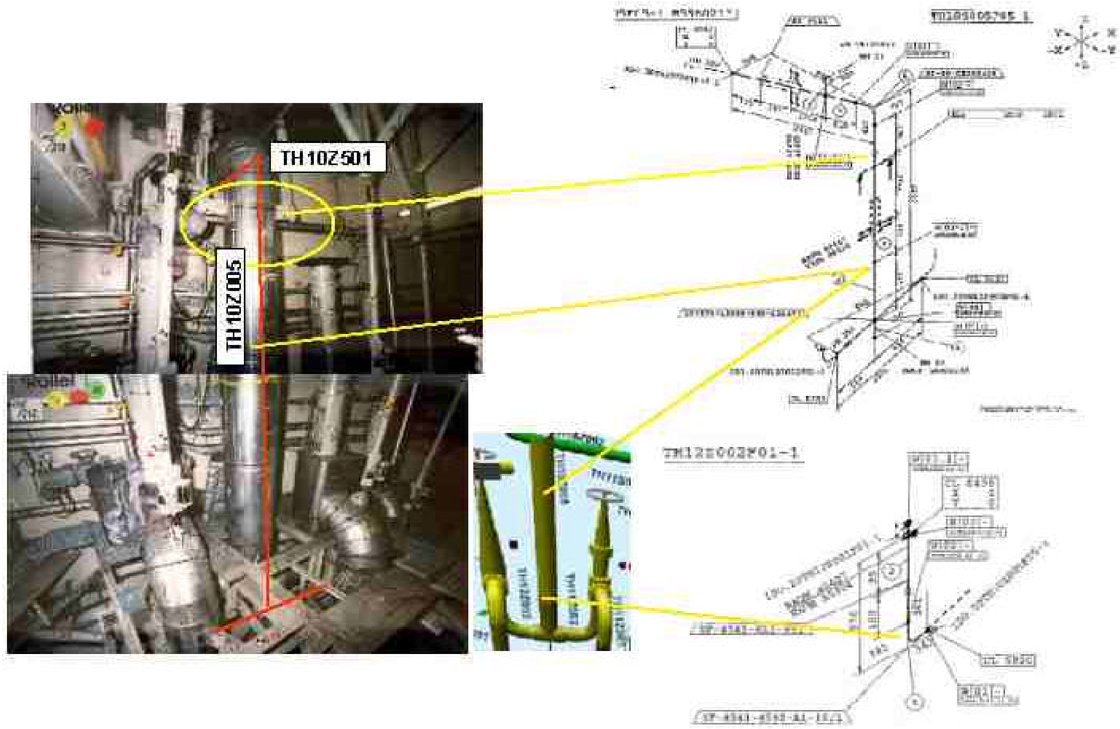

Fig. 6: Display/overlaying of isometric data in the field of vision

3.3.2 Diagnostics and service on production machines

The application scenario of diagnostics and service on production machines has the aim of supporting service technicians and customers with fault diagnostics, commissioning, maintenance, and repair in situ or by direct interaction with the service center using augmented reality technologies and thus to increase the availability of plants (Fig. 7).

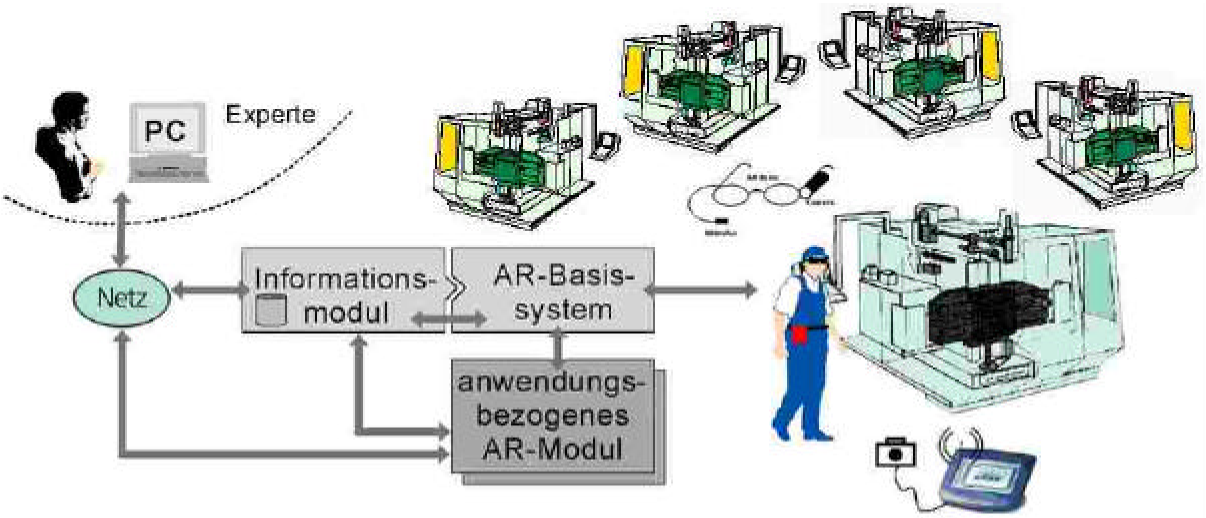

Fig. 7: AR in service

To be able to specify the requirements of the basic architecture and the application modules to be implemented, the problems are analyzed that occur most frequently in the area of service/maintenance and that are most difficult to solve. A harmonized scenario that reflects a cross-section of all application scenarios is derived from individual actual application scenarios. It is possible to derive two standard situations from that:

- The customer or service technician has only himself to rely on and must solve the problem with the information available to him
- The customer and the hotline of the manufacturer attempt to solve the problem together.

The functions that have to be implemented to achieve the harmonized scenario are isolated from the actual scenarios:

- Plant information system
- Navigation in, and linking of documents
- Machine history
- Interactive troubleshooting
- Error tracking and feedback
- Interactive video, virtual laser pointer.

The plant information system is used to provide information to various terminals (PC, mobile PC, eyeglass display). This information might be texts, design drawings, circuit diagrams, spoken instructions, or video sequences. This information is available in different formats and is generally closely related. To facilitate the search in such extensive documentation, mechanisms are envisaged for linking documents. If mobile systems or eyeglass displays are used, navigation using voice input makes sense because the technician would otherwise be hampered in his or her actual activity, troubleshooting and repair.

Information that frequently changes and therefore has to be constantly updated, or that cannot be stored in the local plant information system for reasons of capacity, is provided by linking to external systems.

One important component of the plant information system is the machine history in which all changes (conversions, overhauls) and all faults that have occurred are recorded. Using this information it is possible to trace the life of a machine precisely. Troubleshooting is simplified by the information about similar faults that have already occurred. It is also possible to conduct weak point analyses to be able to identify the faults that have occurred most frequently and eliminate their causes.

Analysis of the cause of a fault often takes a long time. That is why the system to be developed must interactively support the technician. With the aid of fault trees, search engines for searching fault databases, or predefined test routines, troubleshooting is to be systematized and therefore speeded up.

Use of a visual channel makes sense to improve communication between the customer's maintenance technician in situ and the hotline, especially if the interlocutors do not have the same native language. In that case, it is necessary to transmit the field of vision of the technician working on the machine to the hotline technician. This would allow the customer to show the hotline known problems on the machine, and the hotline to "look over the customer's shoulder" while he or she is performing the necessary working steps on the machine. For this application, absolute freedom of movement of the maintenance technician in situ is an advantage. To transmit the pictures from the machine to the hotline a camera is required that follows the viewing direction of the technician.

For interactive support of the technician at the machine not only the audio channel is required but also direct manipulation by the hotline technician of visual virtual objects in the field of vision of the technician at the machine. At their simplest, these objects might be pointers or circles for marking positions or machine parts. In visual display of these simple objects both a head-mounted display (HMD) and a facility for remote-controlled laser pointers is envisaged. Both must be remotely operable by the technicians of the hotline. A further step is the display and manipulation by the hotline of text and static and dynamic image information (working instructions, circuit diagrams, etc.) in the field of vision of the technician at the machine. The positioning of the information in the field of vision of the technician must be static with reference to the machine. That means that the changing viewing angle and position of the viewer must be tracked and the image positioning calculated in such a way that the image displayed remains in the required position.

4. AUGMENTED REALITY – BASE TECHNOLOGIES

The basis for all applications are the base technologies to be researched and developed which, because of the industrial application environment, concentrate on a standard architecture for the following topics (Fig. 8)

- Augmented reality
- Interaction models for mobile and "hand-free" forms of work and

- Information management for situation-oriented and process-oriented data access

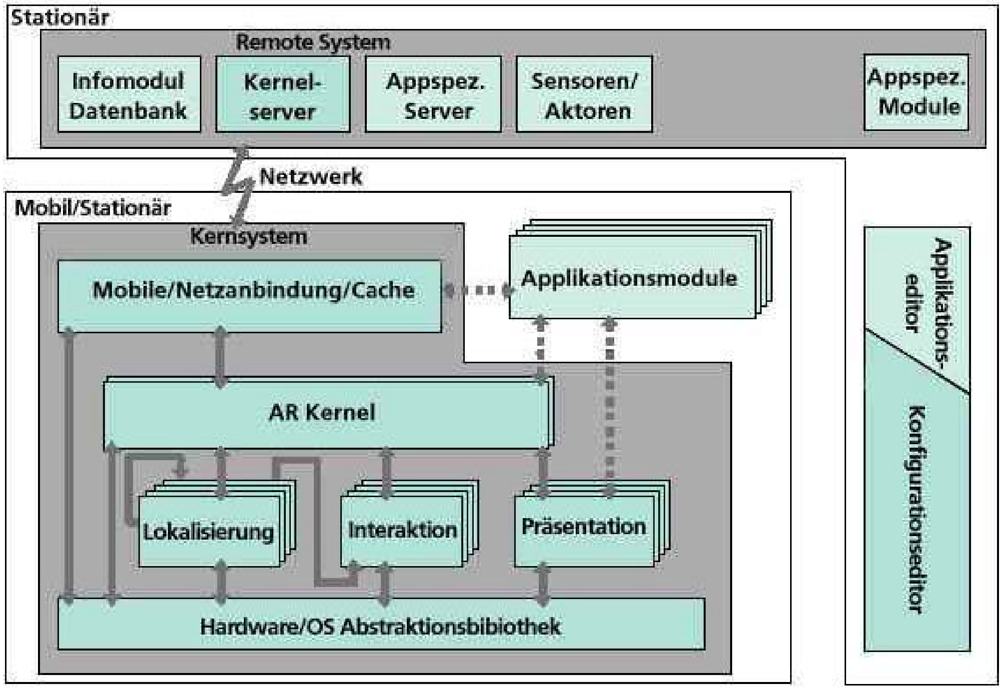

Fig. 8: Augmented reality basic architecture

4.1. Augmented reality

In addition to the challenge of tracking, calibration, and field-of-vision-oriented visualization, the basic architecture must take account of the information models and the information management oriented toward the application-oriented processes. The industrial working environment partially oriented toward the skilled worker limits the possible tracking, i.e. location systems, and makes high technical demands with respect to precision, robustness, and ergonomics. Studies of the tracking systems available on the market and their positioning accuracy are being conducted in an experimental set-up relevant to ARVIKA. For image-based trackers, wide-ranging research and development work is being initiated. We are also investigating to what extent combining several sensors (hybrid tracking) can contribute to solving the problem.

4.2. Interaction models

"Hands-free" work and field-of-vision-centered information display require research and development of new application-oriented interaction metaphors. The use of speech in tough industrial environments must be attuned to the user group and its relevant vocabulary, but also to the display of information in the user's field of vision, which is restricted to the essential information. Navigation, selection, and guidance are processed in the context of the information overlaying reality. Because mobility and unrestricted, but task-oriented information access is a precondition for industrial augmented reality, a mobile network link (data transfer rate, response time), i.e.

integration into wireless networks, is being worked into the interaction model and tested.

4.3. Information management

Industrial AR applications are part of a mainly well established IT environment and are based on the most varied sources of information. They range from simple data sheets to 3D information from product data management systems. Connection to existing information systems and specifications and implementations of AR-oriented data structures are being elaborated in the ARVIKA project to fulfill the precondition for providing the information required for augmented reality in a way which is suitable for the problem and situation.

5. ORGANIZATION AND MILESTONES

The ARVIKA project structure reflects the main topics of the project. Technical management is performed by the subproject leaders and leaders of the large work packages. The management board decides on organizational and strategic questions. The project is advised and supported by an advisory council consisting of top managers from industry and science. Employees' interests are taken into account by the collaboration of the unions in the project.

The total project period is four years (7/1999 – 6/2003) divided into two sections, each resulting in prototypes. Two points are significant in the scheduling of the project:

- Early customer feedback, i.e. feedback from the users in the project
- The possibility of separating off subprojects during the project period to allow implementation of initial product ideas in parallel with the project.

With such a new technology so closely connected with human beings and processes, there is only any real chance of user-oriented development if the user, that is, the skilled worker, is early on given the opportunity to incorporate his or her experience, personal sentiments, and therefore to influence development. Moreover, interaction with the process determined by the customer is absolutely necessary to ascertain what effect reality and augmented reality controlled by human beings have.

To control the risks of the project - especially the financial risk - the industrial partners in particular insisted that at about half-time an extensive review of technical and economic feasibility, customer acceptance, and the situation on the world market be conducted.

6. THE CHALLENGE AND THE CONSORTIUM

The challenges of this application-oriented research project are investigation of the base technology functions, acceptance by a critical user group, and IT integration into the work process. Also the comprehensive range of applications and an aggressive market place high demands on the architecture and development dynamics.

The leading German research institutes are facing up to the challenge of localization and presentation. The new form of interaction with voice, field of vision display, and mobile "hands free" work is being working on by interdisciplinary teams from research and industry. With the parallel ergonomic and psychological studies, critical demands of skilled workers as a group are taken into account and included in the development process. To ensure that the right information is at the right place at the right time, the industrial partners are working on an AR-supporting information management system with the support of R&D partners in the relevant sectors.

The difficult challenge of finding an overall architecture with a common platform concept that supports the high-end applications in development laboratories and mobile applications in workshops and process plants is being met by the consortium with an interdisciplinary architecture team bringing together different points of view. Continuous market research and worldwide cooperative agreements ensure use of state-of-the-art technologies and prevent uneconomical duplicated and parallel development.

An interdisciplinary consortium, comprising several business sectors, is ensuring that the objectives, which are ambitious both from the scientific point of view and with regard to determining the requirements and testing in industrial applications, will be achieved:

- Corporations in automobile manufacture and aircraft construction: DaimlerChrysler, VW, Audi and Ford
- Mid-sized businesses in the machine tool and production machine sector, such as DS Technologie, Hüller-Hille, Gühring, Index, and Ex-Cell-O
- Integrators, service providers, and small businesses, such as A.R.T., UID, and VRCom
- For IT technologies: Fhg-IGD, ZGDV, and TUM, for the applications: the Werkzeugmaschinenlabor WZL and the Institut für Arbeitswissenschaften IAW of the RWTH Aachen and
- Siemens as a user, integrator, and head of the consortium.

A word of thanks

This paper is based on the work of the members of the ARVIKA consortium under the consortium leadership of Siemens Automation & Drives. Special thanks are due to all industrial partners who are advancing this project with their application-oriented expertise and the R&D partners from science and research who are providing the methodical and technological basis. This work is also supported and assisted in an exemplary way by the project sponsor Deutsches Luft- und Raumfahrtzentrum in Berlin.