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Augmented Reality for manufacturing planning

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Abstract
The shortening of development cycles demand for efficient methods and tools for the planning of complex production systems. Recently immersive Virtual Reality technologies have been introduced to the manufacturing planning functions. This has lead to a decrease in planning times as well as to the improvement of the quality of planning results. The introduction of various virtual planning tools is targeting the complete integration of all planning tasks and demands an intuitive interaction with complex computer models of machinery, factory-layouts etc. Known methods and tools are limited to a purely virtual representation of planning objects and thus require the complete modeling of the production system. The high costs reduce the possible benefits of these tools and this technology in general. New potential for the improvement of the industrial planning process are offered by the AR-technology. Using AR-techniques an physically existing production environment can be superimposed with virtual planning objects. Planning tasks can thus be validated without modeling the surrounding environment of the production site. In this contribution we discuss the support of manufacturing planning tasks with the Augmented Reality technology. We present potential benefits and describe the development of an prototypical AR-System for the support of planning tasks.

Keywords:
Augmented Reality, Manufacturing Planning, Visualization

Categories and Subject Descriptors (according to ACM CSS): J.6 [Computer-Aided Engineering]: Computer-aided Manufacturing; I.3.7 [Computer Graphics]: Virtual Reality

1. Introduction

Manufacturers are facing shortened product life cycles caused by rapidly changing customer demands. This leads to the growing need for flexible and fast reengineering cycles of production facilities. Electronic planning tools help to decrease the reengineering time of plants and plant equipment. Through the continuous pressure for rationalization these virtual tools become an integral component of the core processes of manufacturers. Different tools are used to plan plants, machines and manufacturing processes. Examples of these tools are CAD-systems for the machine design, the use of simulation systems to simulate the material flow and layout design systems.

Data generated by the layout design system are of special importance, since other systems (e.g., simulation systems) use the factory layouts as basis. As a result of the performed virtual planning activities factory layouts are generated either in 2-D or 3-D. The quality of the stated representation of the real factory is crucial for succeeding planning activities like material-flow simulation. Frequently the stored layouts are not representing the real factory surrounding. This leads to defects within the planning process and therefore to costly replanning activities. Existing approaches to validate the results of the different planning activities combine the data using Virtual Reality techniques. A true comparison with the real factory environment is very time consuming. To improve the effectiveness of the entire planning activities the need for a system that validates planning results on the bases of real manufacturing environments can be derived.

2. Augmented Reality

The term Augmented Reality (AR) is used to describe systems that superimpose computer-generated information onto the real environment. This combination can be multisensory and might include the enhancement of an image with virtual annotations, the detection and amplification of soft sounds or the use of haptic feedback to increase touch sensing. Unlike Virtual Reality (VR), AR enhances the existing environment rather than replacing it. Transferring Milgram's [1] idea of a reality-virtuality continuum to the assembly domain, it can be stated that the Virtual Reality Technology (VRT) is often used in the early state of the life-cycle of an production system; however, AR is predominantly used in the control and maintenance phase. A strict separation cannot be made.

2.1. Industrial applications of AR

The One of the most well-know applications of AR in the assembly domain is the assembly of cable harnesses at Boeing [2]. In the field of automobile production, applications have been introduced for assembling car doors [3] and for the assembly, commissioning and quality assurance [4] of cockpit modules. Applications of AR for maintenance are also known [5]. Sharma and Molineros [6] investigated an information presentation scheme for Augmented Reality stimuli in assembly. To provide AR contents more easily, Neumann [7] suggests a separate description language. An AR system for testing product prototypes in a mixed-reality environment is described by Balcisoy [8]. In addition to assembly, an application to support dismantling processes is also known [9]. Most research applications are AR prototypes that were implemented for special applications. To be used in assembly, AR applications must be flexibly designed on the one hand, in order to enable easy adaptation to different tasks, for example. Initial attempts to flexibly design AR systems were presented e.g. by Klinker [10]. On the other hand, it is necessary not only to consider the presentation and structuring of the information but to take into account the entire planning process, from the creation of the AR contents to the adaptation of the system to the assembly task.

Here it is especially important to reuse information from computer-aided planning efficiently and to support the planner methodically and with software technology.

3. Requirements

Based on the demonstrated potential of such an supporting AR-system for factory planning, the system requirements will be derived and explained. By using an intuitive user interface the planner should visualize different production systems or equipment directly within the factory hall. In addition he should be able to conduct replanning activities without any additional device or activity. The visualization has to be context dependent and congruent with the real environment. Therefore a Head-Mounted Display (HMD) in Video-See-Through is used. A marker based optical tracking system registers the necessary markers in the real surrounding. This requires a systems suitable to production environments. This means the ability to handle the specific light conditions of a production site. It needs to be robust and mobile for a use in such an environment. The AR-System must assure an easy, secure and reliable integration into the different existing planing systems. The planner needs the ability to connect through the AR-System into other data-warehousing systems, that contain other planning information. The main task of the AR-system is the reception of the information about the marker in the reality and to derive the different 3D-positions of virtual objects from this basis. This task has to be performed very fast and without any external manual assistance. In addition the flexible connection of the different tools to such an AR-system is a basic need. The connection of the different tools of an existing engineering function within an company represents a major success factor of the AR-system. The tremendous amount of calculations of the different transformation matrixes, the different input-channels require high computing power. In addition to this the following general requirements for industrial AR-Systems have to be encountered [11]. The AR-system must display the used colors, surfaces, propositions of the different objects correctly to grant a very high rate of recognition by the user. The AR-system must be able to read and write all common data formats of the used systems like PDM-system, CAD-system, text, pictures, videos etc. This connection has to be implemented via standardized interfaces. The control panel of such an AR-system is limited only to a few steps within the dialogs and the usage of easy readable graphical symbols.

The AR system should be web-based. This grants a maximum flexibility for the use in different system environments. Based on these requirements and derived from the different tasks a AR-System has been developed. It was designed as tool to support the planning process on the shop floor.

4. AR-Plan - AR-based factory layout planning

A way to set up such a system is the superimposition of virtual planning results onto the real manufacturing environment using a HMD (Figure 4). With the visual combination of virtual planning results and real manufacturing surroundings users validate the generated data by easily comparing different geometries, either from reality or virtuality. This enables the user to validate the planning results fast and to change the plans according to the results of the comparison. This process improves the data quality and thus avoids replanning activities. An example that shows the benefit of the described technique, is the overlay of an existing, virtual model of a welding-robot with the corresponding factory environment. Possible collisions of the robot's arm with elements of the factory-structure can easily be identified. Furthermore the technique can generate a closed control circuit between virtual planning and real manufacturing environments.

4.2. System setup

The AR system for planning purpose was set up as web-based client/server-architecture consisting of two different levels (Figure 1). This approach facilitates the access from each connected workstation or computer to each other planning system within the LAN. In addition this set-up reduces the load on the mobile computers. The necessary calculations that require high performance computers, may operate as servers. As client systems different systems were tested. There were two mobile systems (Web-Pad, Siemens and Wearable-PC, Xybernaut) and one stationary PC used in the set up. With respect to the special task the information is displayed in a HMD, touch screen or with a projection system.

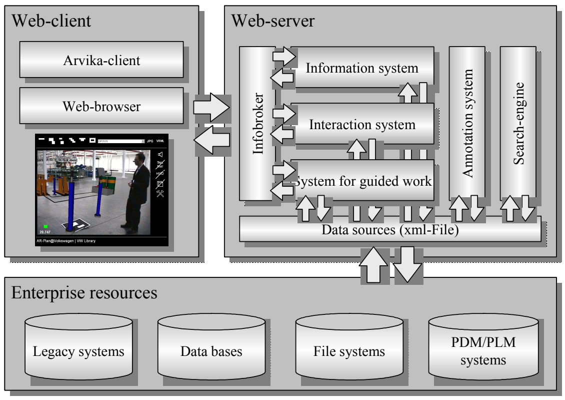

Figure 1 *Client-Server-Structure and system setup AR-Plan*

A LAN build the communication line between the server and the different client computers. The mobile systems were connected via wireless-LAN. Within the network the standard TCP/IP-protocol is used. The webserver is a Apache-Tomcat-Server on which the ARVIKA information system is installed [12]. To visualize the information an integrated AR-Browser (ActiveX-Plug-in) is used on the side of the server. It was developed by the ARVIKA-research project. In addition to these elements a Microsoft Internet Explorer 5.01 or higher is used.

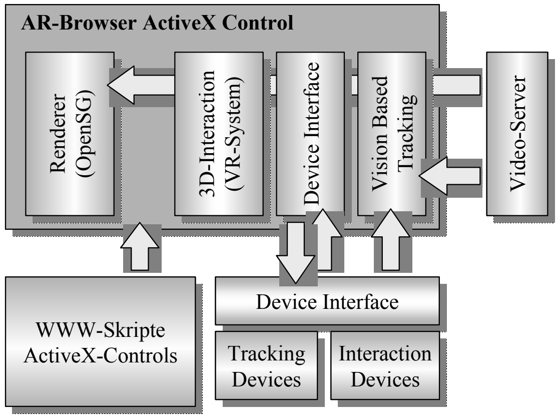

Figure 2 *AR-Browser Plug-In*

4.3. System Components

The described AR system for planning tasks incorporates three main components: Information system, Interaction system, System for guided work. The task of the information system is to supply the information which is relevant for the respective situation. The planner retrieves all necessary data during his time at the production-site. The information is displayed context-sensitively and thus derived from the actual task. Possible data-formats are text-files, pictures, movies, drawings, animations etc. The user is able to search additional information in connected systems. This feature improves his access speed to information on one side. On the other side he stores new information faster. The task of the interaction system is the visualisation of congruent superimposed virtual information onto the real environment. The recognition of virtual objets is implemented using a Vision Based Tracking-System in combination with several square markers. Each marker may be linked to a different virtual object. The allocation is done through a simple menu to support the required flexibility. Standard components from single robots up to entire production systems are stored in connected databases. By shifting a marker, the virtual elements will be moved in the scene. This is one feature that enables the user to perform replanning activities and interact with the system. The system for guided work contains different procedures, which have to be followed to perform a specific task. For each of the described steps the required information is supplied. In succeeding work steps various planning alternatives may be analysed and evaluated.

5. Applications

Interactive table-based planning

One possible application of the developed system is the optimization of factory-layouts.

The planning personnel is used to discuss and improve plant-layouts using paper-based plans. We have enriched this scenario by superimposing three-dimensional objects onto an existing paper-plan. This application is comparable to the Magic-Book metaphor by the HitLab [13]. Using web-technology a cooperative planning-scenario incorporating distributed participants can be implemented. Besides the virtual planning objects participants can access various relevant documents like drawings, spreadsheets etc. We have tested the scenario using an actual planning problem of an automobile plant. Users were able to intuitively interact with the virtual objects. Figure 3 illustrates the actual setup.

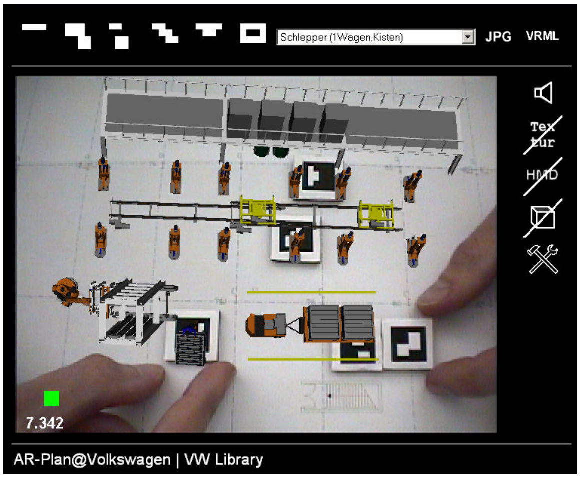

Figure 3 *System-up AR-Plan*

5.4. Visualization on the shop floor

Another powerful application of the developed system is the visualization of virtual machinery or components in the real factory environment. Within the planning-process various fringe-factors have to be considered. A late rearrangement of certain objects like housing, power-connections or machinery can result, due to various dependencies, in high costs for the operator of facility.

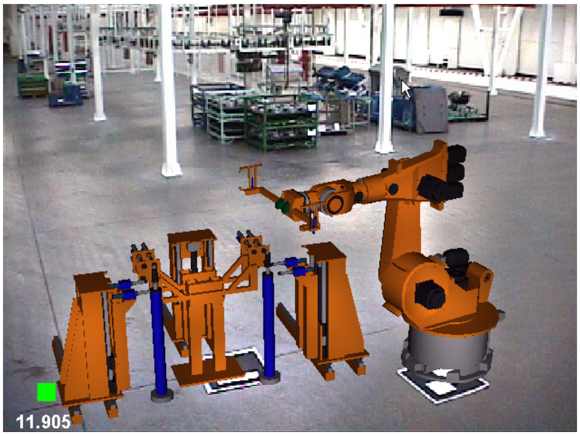

Figure 4 *Visualization of virtual robots and machinery in an plant-environment*

With the developed System the user can interactively load virtual content into the manufacturing environment. The system is connected via a standard Web-Server to the digital-manufacturing-library (Figure 5). The Planner can thus access the enterprise resources (databases, planning libraries etc.).

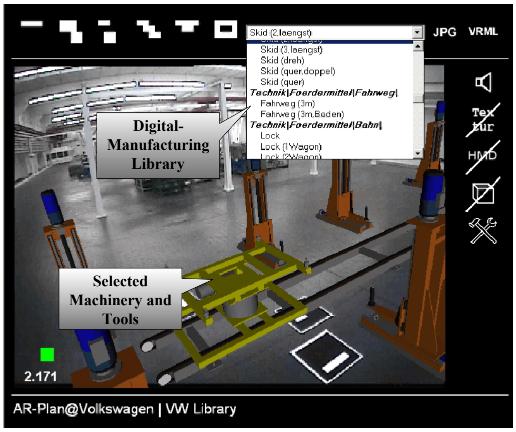

Figure-5: Interactive retrieval of augmented content from company resource management systems

5.5. Measuring

While visiting the factory, the planner has to gather additional information. One example is the task of measuring distances or positions of machinery. To support this task, we have integrated a simple measuring-routine into our system. To measure the desired distance the user of the system chooses a two points in the live video. These points can either be points on the virtual content (i.e. robot) or in the real environment. The system retrieves the coordinates of the points in relation to the coordinate-system of the marker. It then calculates the relative distance of the points. The implemented function can be used to gather rough estimates of geometrical proportions and distances in the factory environment.

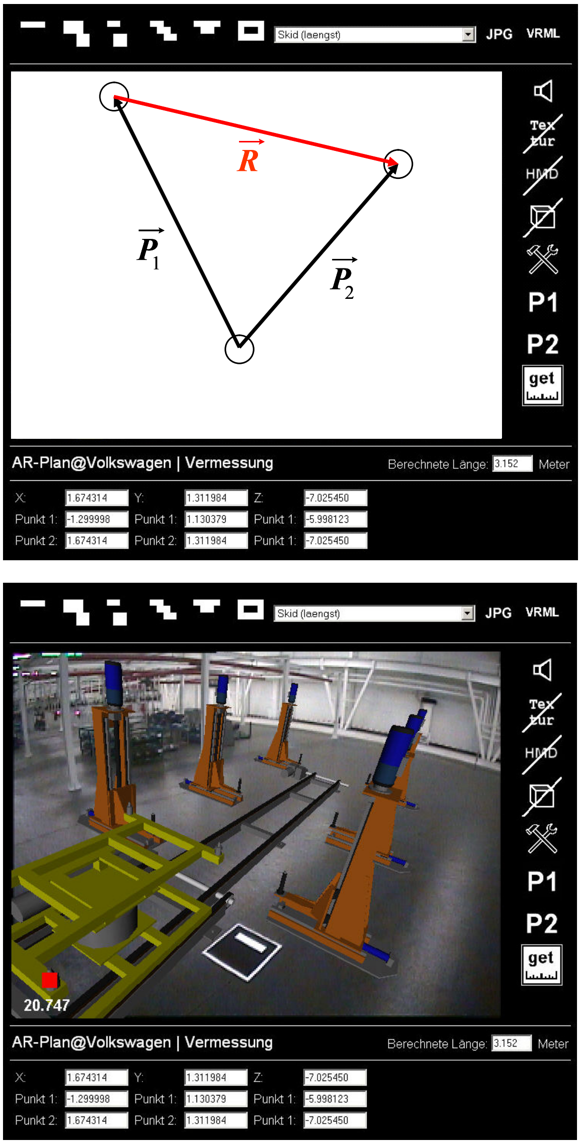

Figure 6 *AR-based Measuring System*

5.6. Workplace ergonomics

The analysis of workplace-ergonomics can be supported with 3D-Simulation-Software. For the evaluation standardized Methods are documented. One challenge using these methods and tools is the time-consuming modelling of the workplace prior to the evaluation.

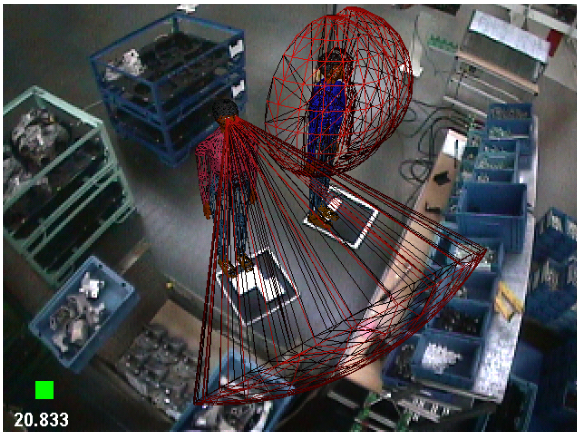

Figure 7 *Manual assembly-workplace with superimposed human degrees freedom*

For many ergonomic and manufacturing-problems the modelling of the workplace is to costly, even more, since many reengineering activities are done on a tight schedule. Nevertheless an ergonomical layout of the manual workplaces is crucial for the production-personal. Using our system, boxes, tools and material can be positioned within an optimized range for the production worker. By combining and superimposing the result of the ergonomic-simulation process we can optimize the manual-workplace without modelling the workplace. The production personnel can participate in this process. Various rearrangements can be benchmarked.

6. Conclusions

Our Augmented Reality supported manufacturing-planning system significantly improves the interaction of the planning person with virtual planning objects. Several field test with planning engineers have demonstrated other benefits like cost-reduction and quality-of-data improvements. For the creation of effective AR applications in production-surroundings, a further improvement of existing Head Mounted Display systems and vision-based tracking-systems is crucial.

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