AR-Planning Tool - Designing Flexible Manufacturing Systems with Augmented Reality

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Abstract
The technology of augmented reality (AR), as a new user interface, introduces a completely new perspective for the design of technical manufacturing systems. This technique supports a face to face collaboration where users need to be able to easily cooperate with each other. As with typical construction sets like LEGO or Fischertechnik, the planning engineers model the future manufacturing system in their real environment. The components are taken from virtual construction sets and are positioned interactively in the manufacturing hall. Planning rules are used to assist the user and to prevents possible errors. This article describes the conception of a virtual construction set and the realization of its prototype. The description of the development of this construction set is supplemented by an illustration of the used hardware and software components.

Keywords:
Augmented Reality, AR, construction set, manufacturing planning, user interface.

1. Introduction

The planning of manufacturing systems includes the design of new production systems as well as the optimization and modification of existing systems. Today the consumer market is defined by high dynamics and short innovation cycles. This postulates a fast and flexible strategy for planning the products and the corresponding manufacturing systems. Therefore the planning of manufacturing systems is becoming more and more a continuous task with time being a critical success factor. In industrial companies this necessitates a large investment of time and money. Due to ever shortening product lifetimes the pressure of time and cost is intensified.

As a consequence of this pressure, today many industrial companies use software tools in their manufacturing planning process [3], [5]. These tools contribute to shortening and improving the quality of the planning process. 3D-CAP software (e.g. *eM-Workplace* from *Tecnomatix*, *IGRIP* from *DELMIA*) could be used for the planning of manufacturing systems, particularly in the micro or fine-layout planning stages [1], [2], [4] (see figure 1). They enable the planning engineer to place machines, handling devices and the corresponding assembly lines in the planned hall. Therefore 3D-models are used to represent these objects in the virtual world. They can be moved and positioned interactively to design and determine the configuration of the manufacturing structure. Other software tools for material flow simulation (e.g. *eM-Plant* from *Tecnomatix*, *WITNESS* from *Lanner Group*, *QUEST* from *DELMIA*) allow the planning engineer to make concrete statements about the pass times of the products, process cycles or the throughput of the whole manufacturing system (see figure 2). Hence, control programs for installed machines, transport and handling devices may be developed offline [6], [7].

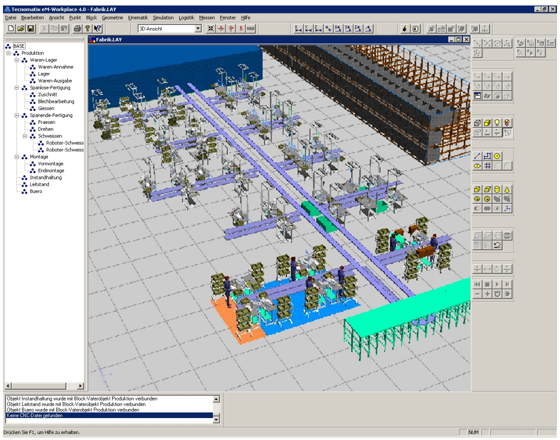

Figure 1: *User Interface of a 3D-CAP-system (eM-Workplace from Tecnomatix)*

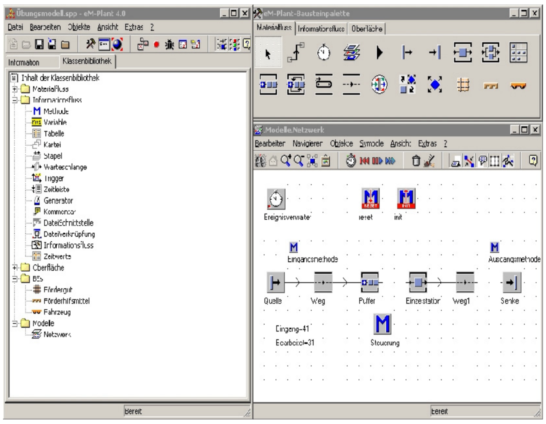

Figure 2: *User Interface of a material-flow-simulation-system (eM-Plant from Tecnomatix)*

On the one hand the afore described software tools are a great utility because they support the user in planning and visualizing the manufacturing system. On the other hand they have one major disadvantage: only experienced and long trained experts are able to operate with these software tools.

The graphical user interface is very complex and not intuitive to use for persons who are not familiar with the software. This necessitates a long tutoring and learning period for an effective use.

Generally a large group of persons (managers, planning engineers, foremans, workers at the assembly line, etc.) from different departments of the company is involved in the planning process. Due to this fact it is obvious that these persons have different preparatory trainings. So the software tools must meet the requirements of all enlisted persons in the planning process.

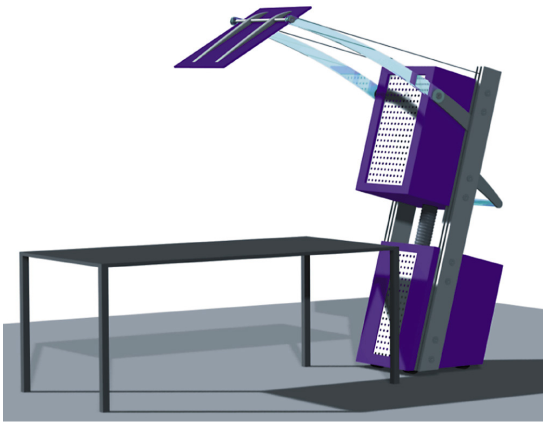

Figure 3: *Build-It - a team based system for manufacturing planning (Frauenhofer Institute, IPA)*

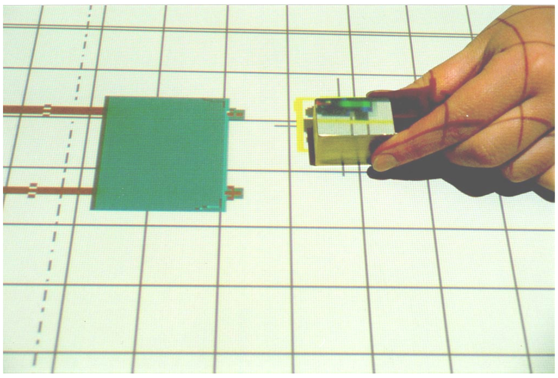

Figure 4: *Physical bricks are used to select and manipulate virtual objects (Frauenhofer Institute, IPA)*

This approach was pursued at the Frauenhofer Institute IPA in Stuttgart where a team based manufacturing planning system called *Build-It* was developed. Using a desk and a number of bricks a group of persons can simultaneously interact with the system. By using the bricks as a mouse virtual machines or handling devices can be placed and moved across the desk. A virtual 2D sketch of the planned manufacturing system is shown on the desk and a virtual 3D-scene is shown via video projector on the wall (see figure 3, figure 4).

But this basic approach is limited in its application. When looking at the desk the user gets no spatial impression - only a two dimensional sketch. Therefore the user has to do two tasks simultaneously:

- He has to look at the desk to catch and to move the bricks.
- To get a spatial view he has to look at the wall to see the whole planned scene in 3D.

The effect is that the user has to turn his head from the desk to the wall multiple times. Each of this head turns necessitates an interruption of the workflow and a reorientation for the user.

The system provides no planning logic (e.g. representation of the active areas and safety margins, faultless composition of the machines or snap functions between the machines) which would increases the planning certainty to a high level. Furthermore it is necessary to use a database for management tasks. This database must be able to import 3D-models of the machines and the corresponding data sheets to automatically generate new planning rules for the machines.

The level of immersion of all the previously described systems is low and 3D-facts are modeled and displayed in only two dimensions (mostly on a computer monitor). So the spatial sense of the users is not supported and thus the frequency of mistakes during the planning process increases.

Augmented Reality (AR) suggests a new solution to the afore described problems. It relies on a new generation of human-machine interfaces. With the help of innovative, small and cheap input and output devices, these interfaces enable the user to immerse himself in a new reality which is augmented with further computer generated information. The introduction of AR as a new user interface for 3D-CAP systems enables a completely new approach to the development of manufacturing systems.

2. Concept of an AR-based Manufacturing Planning System

The method of using construction sets was applied to the development of a manufacturing planning system. Essential components of the augmented reality construction set are 3D-models of machines, devices or transport systems. These can be created by using conventional 3D-CAD-systems or other modelling tools like M*ulti-Gen* from P*aradigm*. A database is used to store and manage the 3D-models, the description of the machines and the corresponding planning rules.

Using Augmented Reality as a new user interface, the user can select, place and manipulate each component of the construction set in an easy and intuitive way. This increases the usability of the tool.

2.1 Construction Functions

2.1.1 Collaborative planning

The basic task of the system is the layout design of a manufacturing plant. Like the table-top AR-application from the *HitLab* of the *University of Washington* [8], the user is able to design the layout by choosing different objects like machines from a catalogue. With a tangible user interface he has the possibility to place and move the objects in a VR model of a plant. It permits even non experts to work with this tool without prior training.

As a table-top application it is possible to use the tool like the planning system *Build-It* [10] to allow a collaborative working for a large group of persons. It is not necessary for each user to wear a HMD, as the scene is shown via a projector on a screen. The advantage of this system is the spacial impression for the user. He works with 3D-objects, he observes these objects in the right perspective and can walk around the table, in order to see the whole scene from every direction. To take part in a collaborative planning session every user gets a HMD and a different tangible interface. For each HMD a single PC is used to render the scene from the corresponding viewpoint. The management of the total scene is done by a single server. The other PCs act as clients - they send the single user actions to the server (viewing direction, scene modifications) and receive the new updated scene. Due to the usage of different tangible interfaces the activities of each user during the planning process can be stored.

2.1.2 Planning Rules

The integration of planning rules allows a computer supported planning process with a high degree of faultlessness. Among others the following planning rules are established:

- Representation of active areas and safety margins
- Consideration of workspaces
- Composition rules for machines
- Adherence of minimum and maximum distances between machines

The consideration of these planning rules is implemented using different types of attributes with a set of corresponding parameters. The attributes can be assigned to each machine which is available during the planning process. Only those machines which have an accordant attribute can be assembled to a single coherent manufacturing area. In this case the selected machine is placed in the correct orientation and distance towards the consisting machine, considering the safety margins and workspaces.

The representation of active areas, safety margins and workspaces is realised using bounding boxes whereas the consideration of the composition rules and the adherence of minimum and maximum distances is done by snap functions. Thus the consideration of power supply for electricity, air and water is possible.

During the layout planning the engineers use grids to divide the plant ground: coarse grids for rough planning and fine grids for detailed planning. In addition to this water, air and power supply lines are displayed on the grid and should be taken into account.

2.1.3 Database

The database manages the 3D-models of the objects and the corresponding data sheets. During the planning process the database manages the updates of the scene.

After an object has been modelled, it is stored in the database and the user has to fill out a datasheet. This

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datasheet contains information about the properties of the object which are described in the chapter before (e.g. active areas, safety margins, etc). Furthermore attributes for the planning rules can be set. They contain information about snap ranges, connection points and which objects can be assembled. For a following material flow simulation the datasheet contains information about the transmission behaviour.

2.2 Simulation of the Planned Manufacturing System

Apart from static layout design, the design and the optimization of technical manufacturing processes is extremely important. In this case the process simulation is used for designing material flows and logistics. Therefore the following three simulation scenarios are created.

2.2.1 Scenario 1: Simulation within the AR-System

The graphic of the prototype bases on the VRML 2.0 graphic standard. This allows to use animations aside from static objects to show the behaviour of the machines. For example it is possible to show the movement of a robot in his later environment in order to visualise its active space or to detect possible crashes with its environment.

2.2.2 Scenario 2: Simulation using External Programs

The results of the layout design are stored in the database. They contain information about the position of the objects and their transmission behaviour. This data can be used by discrete simulation tools like *eM-Plant* from *Tecnomatix* to simulate the material flow in the planed factory. Thus the regarding throughput, the disrupt ratio of the system and the expected production capacity can be predicted.

The total model containing the manufacturing hall and the interior can be exported to VRML. Then the whole scene can be imported in 3D-realtime rendering systems for an higher degree of immersion. In the realtime environment additional interaction between user and 3D-scene can be implemented like interactive walkthroughs or the visualisation of information flows.

2.2.3 Scenario 3: Simulation in Real Environments

After the configuration is designed with the AR-based construction set, it can be verified in the real environment using a wearable AR-system. This system blends the before designed manufacturing system into the real manufacturing hall.

In general the tracking of the user is the main problem, because the machines in production environments cause interferences to electromagnetic trackers or other hybrid tracking systems [11]. To avoid this effect optical tracking methods are utilized: attachment of optical reference points on pillars and on the ground.

The occlusion culling problem (e.g. a real pillar overlays a virtual machine) is solved by using a 3D-model of the existent manufacturing hall. Before the real scene is conflated with the virtual machines, this 3D-model is used as an alpha-channel.

3. Realization of a Prototype

The prototypical realization of the AR-based manufacturing planning system bases upon the *ARToolKit* software from *HIT Lab*. This prototype will be upgraded further on to support all the itemized functions described in the previous chapter.

The current version of the prototype supports the following features:

- **Construction Set**
  The user can select different machines and devices from a virtual construction set. They can be selected, positioned and moved using a paddle.
- **Planning Rules**
  A number of planning rules like the snap function or the consideration of safety margins and active areas increase the planning certainty and ease the planning of complex manufacturing systems.
- **Load/Save of Planning Stages**
  Actual planning stages can be saved and restored using an internal file format. Till now the user enters his commands via shell input.
- **Export of Planning Stages**
  Planning stages can be exported into VRML 2.0. Based on this format the user can convert the data into several other data formats to use it by other applications (e.g. 3D-realtime rendering systems).

3.1 Hard- and Software Environment

The planning environment with the virtual construction set is generated and controlled by a PIII 933 MHz PC equipped with 512 MB RAM and a *GForce II Ultra* graphics card. As output device a *Olympus Eye-Trek FMD 700* with two attached cameras is used to get a stereoscopic image. At present a first porting of parts of the system on a wearable (*Espresso PC*: PIII 800 MHz, 512 MB RAM) is performed.

The current prototype was realized using the software *Magic Paddle* from *HIT Lab*, which is based on the *ARToolKit* software [8], [9]. The system offers the development of table-top AR environments using markers for tracking.

3.2 Working with the Virtual Construction Set

Having started the application, the user (equipped with a HMD) finds himself in a scene such as in figure 5. The machines and devices of the virtual construction set are stored in a kind of book. Using a paddle, modules from the virtual construction set (see figure 6) can be brought into the future manufacturing hall and assembled with help of construction functions. If the pieces to be assembled are brought close enough to each other, they snap together (having the correct distance and orientation).

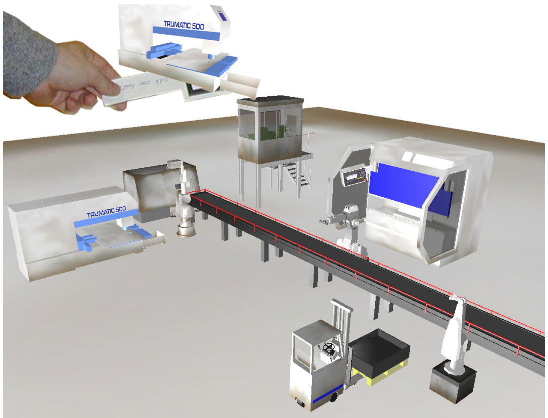

Figure 5: *Placement of a selected machine in the planned manufacturing hall*

Figure 6: *Book like construction set from which the user could select machines or devices*

Hence the user is now able to build up a manufacturing system straightforward using planning rules to ensure the correctness of the planned system. During the planning process all stadiums can be stored (into an internal format) and exported (into VRML 2.0). Those may then be inserted into a VR scene and can be displayed as seen in figure 7 by a 3D-realtime rendering system like *RealiMation* or *DIVISION MockUp* [12].

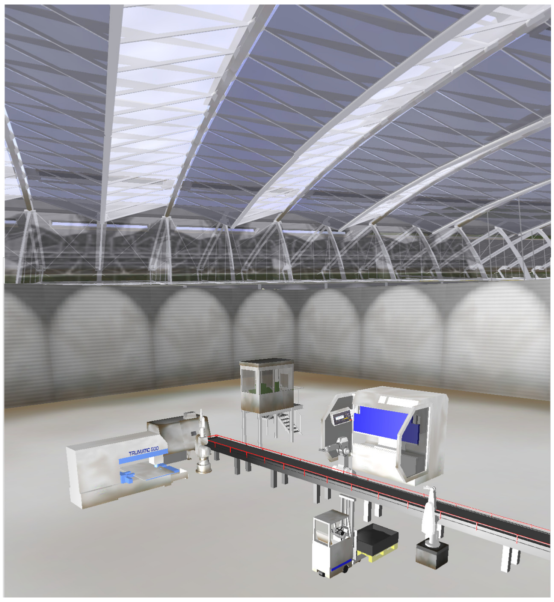

Figure 7: *Virtual reality scene containing the planned assembly line*

Here you can see the assembly line in a virtual factory. This scene is created using the 3D-realtime rendering system *DIVISION MockUp*. A simulation/ animation of the whole system has been carried out using key frame animation.

4. Usability and Performance Tests

The feedback of the trial testing of the first prototype confirms the demand of new user friendly and easy to use interfaces. In several trials the involved planning engineers needed only a short time of 5-10 minutes to understand the functions of the AR-based user interface.

Unfortunately accurate placements, movements and alignments of the 3D-models in the AR-scene are very difficult to realize, because a slight and exact touching of the 3D-model with the paddle is hard to perform. If the planned manufacturing system consists of a high number of 3D-models which are densly placed, it is not easy to select and move a single 3D-model without touching and moving the other adjacent 3D-models. So at this time the AR-planning tool can only be used in the first stages of manufacturing planning i.e. for the rough planning. On that score we want to implement a freezing-function which allows the user to move one 3D-model whereas the other 3D-models retain their current position and orientation.

Using a marker based tracking method, it is necessary to warrant an adequate lighted up environment, whereas no mirroring or dazzling surface should appear. Otherwise a lost of tracking could accrue. Therefore we want to integrate the forthcoming version of the *ARToolKit* to get a better tracking quality.

The live video is captured by two small and light C-MOS camera modules which are integrated into the HMD. Because of their small size they have only a maximal resolution of 480*340 pixel. This results in a low resolution image quality of the HMD (even though its resolution is 800*600 pixel). To overcome this lost of ergonomics two high resolution cameras should be used for the next prototype.

4 Summary and Outlook

In this paper we illustrated the disadvantages of up to date computer systems which are currently used in the planning process of manufacturing systems. The disadvantages of those systems are the sophisticated handling and the difficult user interface. Therefore we introduced a new concept of a AR-based manufacturing planning system.

The prototype described above has shown that the use of an AR-based construction set in the technical planning and projection process is beneficial. The efficiency of the system mainly depends on the number and quality of construction elements available in the virtual construction set. The implementation of planning rules assists the user and prevents possible errors which normally occur during the planning phases.

We are currently refining the prototype to implement the complete described concept. In this context a AR-based menu system will be developed.

The next step will be to verify the previously developed manufacturing system in the real environment using a wearable AR-system (see figure 8).

Figure 8: *Examination of the developed manufacturing hall in a real environment (Opel AG)*

This procedure allows a final safeguarding of the planned system. Now possible mistakes which could not be detected by the planning rules of the system are located and identified.

5 Acknowledgements

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