IMPLEMENTING VIRTUAL AND AUGMENTED REALITY USING DISCRETE MANUFACTURING SYSTEM SIMULATION

Ravi Ahuja  
Student (B.Tech VII sem) Department of Electronics and Computers Engineering  
Dronacharya College of Engineering, Gurgaon-123506, India

Shubham Verma  
Student (B.Tech V sem) Department of Computer Science Engineering  
Dronacharya College of Engineering, Gurgaon-123506, India

Pankaj Singh  
Student (B.Tech V sem) Department of Computer Science Engineering  
Dronacharya College of Engineering, Gurgaon-123506, India

ABSTRACT  
Nowadays companies operate in a difficult environment: the dynamics of innovations increase and product life cycles become shorter. Therefore, companies need new methods for the planning of manufacturing systems. One promising approach in this context is digital factory/virtual production—the modeling and analysis of computer models of the planned factory with the objective to reduce time and costs. For the modeling and analysis various simulation methods and programs have been developed. They are a highly valuable support for planning and visualizing the manufacturing system. But there is one major disadvantage: only experienced and long trained experts are able to operate with these programs. The graphical user interface is very complex and not intuitive to use. This results in an extensive and error-prone modeling of complex simulation models and a time-consuming interpretation of the simulation results.

To overcome these weak points, intuitive and understandable man–machine interfaces like augmented and virtual reality can be used. This paper describes the architecture of a system which uses the technologies of augmented and virtual reality to support the planning process of complex manufacturing systems. The proposed system assists the user in modeling, the validation of the simulation model, and the subsequent optimization of the production system. A general application of the VR- and AR-technologies and of the simulation is realized by the development of appropriate linking and integration mechanisms. For the visualization of the arising 3D-data within the VR and AR environments, a dedicated 3D rendering library is used.

Keywords: Virtual Reality, Augmented reality, Simulation.

1. INTRODUCTION

A constant competition of businesses demands short product cycles and fast changes of products: the dynamics of innovations increase; the product life cycles become shorter; at the same time, the products become more complex; the keen competition forces companies to respond to changes of the market. It is important, that either the production processes are adjusted as quickly as possible to new circumstances or new production processes are planned in the way that they yield the required results straightaway [1,37]. The keywords digital factory and virtual production refer to a new approach, how to cope with the above mentioned challenges [2]. In this context, the discrete simulation of the behavior of production facilities is of particular importance. At first, the development of a simulation model is essential. Therefore, the considered system is analyzed and a computer-internal model is developed. This includes the modeling of functions, processes, behavior patterns or rules, which are to reflect the actual interrelations of effects in a business in this model [3]. The modeled aspects are linked together in the way that all functions of the model represent a whole. For various problems, extensive models with a complex behavior are required. However, an increasing size and complexity of the simulation model lead to more work for modeling, a higher error-rate and runtime, and to more work for interpretation when analyzing the results. Errors in modeling result in misinterpretation and false results in a simulation.
In this context, the design of the user interface is very important [4]. For the usual, little intuitive WIMP-Interface (Windows, Icons, Mouse, and Pointer) highly trained users are required so that the development of complex simulation models involves a lot of time. The simulation results are presented in the form of spread sheets and of two-dimensional, abstract illustrations of the production system. This seems to be adequate for simulation experts, but it is not acceptable for a multidisciplinary planning team consisting of people from diverse departments of a company. Therefore, the development of a simulation tool having more than an intuitively understandable user interface is required.

2. TECHNOLOGIES SO FAR

2.1. VR-technology
The rendering of virtual three-dimensional worlds is made by image computations of abstract, mathematical 3D-models (e.g. polygons) describing a virtual world [42]. In case of real-time-rendering images are computed with at least 20 images per second in order to facilitate navigation in a virtual scene. 3D-rendering systems are programmed via an abstracting interface in the form of a low-level graphic library like OpenGL or Direct3D and they have specific graphic hardware for a fast execution of arithmetic operations. High level libraries (e.g. Open-Inventor, Performer, OpenSG, OpenScene-Graph) support comfortably the programmer with a structured view on the 3D-model data by means of a hierarchically built scene graph when organizing, constructing, handling, and interacting with the virtual 3D-world. PCs with graphic hardware display scenes of up to several hundreds of thousands polygons in real-time. More than one million polygons are often required (e.g. by using 3D-CAD-models). The virtual scenes of manufacturing plants are so complex that they cannot be displayed in real-time on a single PC without the application of specific techniques [5]. The reduction of complexity (approximation) [6–8] and the computation of hidden objects (visibility culling) [9, 10] are two main approaches for real-time rendering.

2.2. AR-technology
Augmented reality (AR) is a new form of the man machine interaction [12]. Computer-generated information is shown in the user’s real field of view. The shown information is context-dependent concerning the viewed object. Therefore, AR can replace the common installation manual, e.g. by showing installation details in the technician’s field of view (Fig. 1).

The position is determined by the tracking system which brings the real and the virtual world together.

This has to be highly precise in order to project the virtual objects exactly onto the real objects. Previous systems use infra-red, ultrasonic or electromagnetic tracking for rotational position sensing. Alternatively, GPS-systems or the inertial position sensing can be used.

Another solution approach is the image-processing systems. They optically identify real objects directly from a video display. One of the mostly used systems is the ARToolKit from HITLab of the University of Washington, Seattle, WA. This system works on specific graphical patterns (marker) [13–15]. There are also first approaches already working without such markers (natural feature tracking) [16–18].

One of the objectives of the AR-technology is the seamless integration of virtual objects into the real world. Here, an occlusion of real and virtual objects is possible (occlusion problem), e.g. a real pillar occludes a virtual machine. In order to avoid this problem, the virtual object is laid semi-transparently over the real image. However, the correct spatial overall impression of the scene disappears here, which eventually leads to confusion of the user [19].

Currently, there are first approaches eliminating this problem by either developing a 3D-model of the reality preliminarily and then using this as an alpha-channel by the image generation of the virtual objects or by identifying the occlusion optically [20,21].

Fig.1. AR-scene: installation details are shown via special glasses in the user’s field of view.

3. CONCEPT OF A VR/AR SUPPORTED SIMULATION
The scenarios described in the previous chapter show that VR- and AR-based tools and user interfaces can be employed during various stages of the simulation study in a useful way. In order to guarantee this utility an integrated overall system has been developed. Its architecture divides the system into five components:

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man–machine interface, event handling, simulator, image generation and integrated data model (Fig. 2). Till now, the components image generation and man–machine interface as well as first parts of the simulator have been implemented.

3.1. Man- Machine Interface
With the integration of the simulation into the VR and AR-environment new forms of interaction and user interfaces arise. A general and uniform user interface is also to be used within the AR- and VR environments offering extensive interaction possibilities. Moreover, a navigation system is used to facilitate the accentuation of places and objects with significant influence on the process of the discrete simulation in the VR- and AR-model by using appropriate illustration metaphors [26].

If a user accomplishes an interaction in an AR- or VR-environment, the interaction will be assigned to the correspondent simulation object. In that way, actions in the simulation can be initiated in both environments.

3.2. Simulator
New standards result from the complete integration of the simulator into a VR-AR-environment. Conventional material flow simulators [25] often offer a 3D-view, but the modeling and the accomplishment of the simulation are normally made in 2D on a computer. The visualization as well as the simulation is carried out on the same computer. This leads to sub-optimal results regarding the image quality and performance. Systems with an exact separation of both are rarely known though [33].

The simulation module must be able to accept the user’s input about the event handling process and to adjust the simulation model accordingly. This applies to both static and dynamic data. In this way, machines are produced, placed, parameterized, and linked. The simulator and the test runs are managed completely from the VR-/AR-environment. If a test run is started, the dynamic data stimulating and controlling the visualization are generated.

Significant points/objects and the simulation of particular interest for the user are to be identified automatically or semi-automatically in order to emphasize important points. A semi-automatic identification is obtained by the targeted introduction of sensors for significant points by the modeler. The modeler has a general idea about a normal simulation experiment. He knows which processes are critical, their typical behavior and which random events generate exceptions, for example a machine breakdown.

He also has an idea about the critical processes and states. This specific knowledge is used at the semi-automated calculation of significant objects. The modeler explicitly sets sensors to detect significant objects, e.g. if a buffer runs empty, the modeler could implement a rule which indicates a significant process.

Fig.2. Structure of the system and its elements.

If such a significance sensor alerts, the belonging object will be rated by the system in a higher significant level depending on the number of parts in stock. In this approach, the responsibility for the correct detection of significant objects is part of the modeler’s work [26]. For example, overflowed stocks or some missing parts for machines can be identified by sensors.

Integrating the sensors into the elements of the library of the simulator allows an implied application of the sensors during modeling. In order to identify more complex, machine-overlapping significances, the modeler has to devise more extensive rules. During running time the simulator holds a model reduced to the simulation functionalities (e.g. without 3D-information), which allows the application of common simulation methods. The application of conventional material flow simulators results in a restriction of the flexibility of the proprietary development. Manufacturer specific problems and paradigms can be avoided in this way. A tool for this is currently under development by the authors [34].

3.3. Image generation
The system of the generation of images is to meet the following requirements: on the one hand, it is to offer scalable graphic’s power with a high performance and
image quality for diverse applications. On the other hand, it is to facilitate an automatic and fast data preparation of the data from other applications that are to be visualized. Both the diverse applications and the data require a specific architecture meeting the varying standards and offering a uniform interface for the user at the same time.

All-purpose solution is needed for the visualization requirements with varying performances existing on hardware platforms in diverse fields of application, e.g. mobile PDA (data capture), desktop PC (simulation), portable notebook (presentation), and PC cluster for high-end VR-systems (large-format projection for a number of persons, see Fig. 3).

Only one scalable graphic’s system must suffice to fulfill the requirements for all platforms. This system allows the visualization of very large and stereoscopic VR-scenes with any topology, e.g. single objects like robots, subassemblies, and product lines as well as manufacturing plants, and production sites. The virtual scenes of manufacturing plants are so complex that they cannot be displayed in real-time on a single PC without the application of specific techniques [5].

The graphic system is to obtain a high-quality, photorealistic display by means of new techniques (e.g. real-time shadows, reflections) and a high performance of the display on various platforms (e.g. PDA, monitor, powerwall).

In order to cope with the different performances of the hardware platforms, a distributed image computation is advisable: the virtual scenes are computed in parallel by a scalable PC-cluster. The computed image data is transferred to the client by an appropriate transmission medium, e.g. WLAN, LAN, and Internet.

In situations without network access to the cluster, the efficient clients (PC or notebook) can undertake a part of the image computation or compute 3D-images on its own for presentations or other purposes. So far, we developed algorithms and techniques for the rendering of highly complex scenes. For the evaluation of the algorithms, we implemented the techniques in a prototypical walkthrough system [35]. With these experiences, we have to build up a scalable system as described above.

3.4. Integrated data model

The outlined system receives data from various sources for/from different modules. In order to avoid inconsistencies and to make adjustments automatically available for all modules the simulation- and visualization models are not to be saved separately. A common pool which can be accessed on-line without restriction is required.

![Fig. 3. Scalable graphic’s power by using distributed image generation techniques.](image)

The exchange of an element, e.g. a 3D-model, is only needed to be done on one spot (either in the AR- or VR-environment) and the modified system will be available in the entire system.

Appropriate interfaces between the data model and the IT-systems are available for the integration in the user’s IT-infrastructure. In this way 3D-CAD data can be taken from the applied 3D-CAD system and simulation models can be exported for standard material flow simulators.

3.5. Automated data generation

The 3D-visualization of CAD-models being developed with CAD-systems, e.g. CATIAV5 from Dassault Systems or HLS-Modul for MicorStation from Bentley Systems, often takes place in a VR-system. At first, the model is exported by the CAD-system, and secondly, it is represented in a VR-system. The viewer can move freely in the model and see it as a whole. In case of CAD-models that are more complex, the entire model cannot be viewed on the computer in real-time. In the field of industrial construction and planning, an intensive process is necessary.

In this context, several problems occur:

1. The format of the data of the CAD-system must be converted into a format that can be handled by the VR-system. The exported data is often incorrect because of bugs in the software or because of the imprecise definition of the 3D-formats.

2. The exported scene is approximated by polygons whereas the user can determine the level of the
approximation. In order to achieve a high precision, a large number of polygons which do not allow a representation in real-time, are necessary. Consequently, a data preparation of the highly polygonal scene usually takes place (the reduction of complexity) in order to facilitate a representation in real-time.

3. The data of the CAD-system is designed for a high precision construction, but not for a visually pleasing impression in the VR-system. So, the visual impression is improved by a mostly manual creation of additional information, e.g. light, shadow, material, and textures.

For all of these three steps, there are methods and programs providing a solution to these problems. However, the intervention of people is necessary in order to do the workings that cannot be done automatically yet. For example, a strong reduction of polygons leads to bugs that have to be reworked manually with 3D-modeling programs. The topology of the scene raises difficulties during the reduction of polygons (e.g. the scene of a production line). Time consuming work-step is necessary in order to be able to see a large CAD-model in a VR-system. This work-step is disturbing, if modifications that are to be shown immediately in the VR-system are made quickly in the CAD-system or in the simulator.

Consequently, a solution is required whereby the first and second step is completely automated and the third step is reduced to a quick and semi-automated process with the help of dedicated libraries (Fig. 4).

This procedure allows an extensively automatic visualization of highly complex data without manual post processing. Suitable algorithms for this procedure have been developed. These algorithms allow a close to real-time display of very complex scenes up to $10^{14}$ polygons. If the main memory is not sufficient, the virtual scene is stored on the hard disk. Even in this case, a close to real-time visualization of the scene is possible. These procedures cannot render more quickly or produce a higher quality of the display then other specialized methods. The advantage is the display of an arbitrarily structured scene (e.g. production lines) without having the need for changes of the structure of the 3D-models. This process is fully automated and does not need any manual rework. The procedures do not have any assumptions of the topology of the scene and provide comparable approximation qualities for different structures.

This procedure allows an extensively automatic visualization of highly complex data without manual post processing.

![Fig. 4. Process of image generation.](image)

The 3D-models used in the AR/VR environment are to be generated from the company internal 3D-data (e.g. 3D-CAD-models). For this purpose, information about colors, material properties, and textures are to be considered. So far, our methods are implemented in a prototypical walkthrough system. The next step is to implement specialized import filters that can read data from several CAD programs.

### 4. CONCLUSION

Nowadays businesses face increasing dynamics of innovations, shortened product life cycles, and a continuing diversification of the product range. Consequently, the planning of production systems plays an important role. Errors within the planning cannot be easily fixed and involve time-consuming and cost-intensive reconstructions.

The described approach explicates that the development and planning of complex production processes and systems can be supported significantly by a VR/AR-aided simulation. The presented system can be applied in every stage of the modeling (actual analysis, modeling, experiments, evaluation, adjustments, and presentation of the solution). In particular the cooperative planning of production systems is supported.

The described concept of an integrated complete system is to be improved in the near future.

### REFERENCES


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