Applying Virtual Reality to Electronic Prototyping - Concept and First Results

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Abstract

Electronic (or digital) prototyping means to use product data models instead of physical prototypes for analyses and evaluations of product design. In many cases, e.g., for conceptual design and product presentation, it is essential to provide the users the impression of using a real prototype. For these purposes, we proposed a concept called virtual prototyping. The idea is to integrate techniques of virtual reality with computer aided design and simulation, to provide an environment, with which a CAD model can be presented and manipulated like a real object. In this paper, our overall concept is described. Some typical examples are presented with discussions about their implementation. Finally, experiences based on these pilot implementations are summarized and future directions of R&D are discussed.

Keywords

virtual prototyping, virtual reality, conceptual design, modeling and simulation, object manipulation, realistic presentation

1 INTRODUCTION

Electronic (or digital) prototyping is an alternative to physical prototyping technologies. Based on CAD model data of a designed product, different analyses can be done to prove and improve design results. CAE systems such as FEM, kinematics and dynamics simulation programs provide very detailed information about a product's function. Of course, these systems are designed for and primarily used by specialized engineers.

In the early phase of product development, e.g. for conceptual design, detailed analysis are not required. More important are features like form, color, placement and some functional features like motion constraints, accessibility etc. Additionally, prototypes are often used in supporting discussions between people with different technical backgrounds. Designer, managers, or engineers discussing about a product design, are used to point on a model directly and say: it could be a peak there. They sometimes want to modify the model immediately and use the new model for further discussions. For such purpo-

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ses, electronic prototyping using CAD/CAE systems based on conventional mouse-menu driven user interfaces is not suitable and sufficient.

Recent developments in computer graphics and computer simulation have now provided more sophisticated tools for electronic prototyping. Specifically, virtual reality (VR) techniques offer the possibility to experience virtual worlds with very high realism. This includes visual and audio presentation and techniques towards intuitive object manipulation. Combining VR with modeling and simulation methods opens new possibilities of prototyping based on CAD models. In the future, it will be possible to take the data model of a product as a virtual prototype instead of a real object to model and analyze geometry, functionality, and the manufacturing of designed products interactively. We call the resulting technology *Virtual Prototyping* [0].

Virtual Prototyping is a method to be used to evaluate different design alternatives very quickly. In contrast to physical prototypes, a virtual prototype is made very fast, can be manipulated and modified directly and the data is reusable. Applying virtual prototyping will rapidly reduce the number of real prototypes and speed up the product development process. This implies a tremendous reduction of development costs.

To implement the idea of Virtual Prototyping, considerable research and development is necessary. Untill now, only a few experiments are known (e.g.: [0]). IGD, the Fraunhofer Institute for Computer Graphics in Darmstadt (Germany), has performed research and development on several related topics and has recently started the integration of techniques and software to develop an environment for Virtual Prototyping. The first results of this effort have been completed, which can be experienced live in the *Virtual Reality Demonstration Centre* at IGD [0, 0]. In this paper, our overall concept of virtual prototyping is described. Some typical examples are presented with discussions about their implementation. Finally, experiences based on these pilot implementations are summarized and future directions of R&D are discussed.

2 VIRTUAL REALITY AS NEW MAN-MACHINE INTERFACE

A virtual prototype must reflect the characteristics of physical prototypes. These are in particular: *optical appearance, spatial presence and dynamical behavior.* Virtual prototypes can be viewed from different angles, scaled to fit in small spaces (e.g. models of buildings and ships) and manipulated with hands. Artistical as well as technical features like form, space, and measurements can be judged. Even characteristics such as stiffness, kinematics, and dynamics appear as spatial changes. Qualitative judgments about the products function can be made by manipulating the prototype and viewing these spatial changes. Therefore, a virtual prototyping environment has to present these spatial information and allow to interact with the designed objects directly in 3D. This can be achieved by using VR as new man-machine interface.

Virtual Reality is characterized by a realistic environmental simulation and the stimulation of human senses to give them a realistic impression of the virtual world. Up to now, considerable progresses are achieved in this area [0, 0, 0, 0]. Typical features of existing VR systems are:

- real-time visualization and auralization
- immersive presentation (HMD, CAVE)

- direct 3D interaction, like navigation, object manipulation, etc. (gloves, tracking systems) [0]

To apply VR to electronic prototyping, thus to implement virtual prototypes, we have to integrate existing VR techniques into the virtual prototyping system and to improve them to fit the requirements of virtual prototyping.

3 COMPONENTS OF A VIRTUAL PROTOTYPING ENVIRONMENT

Our concept of virtual prototyping is based on the integration of modeling, simulation and VR techniques. Figure 1 illustrates the proposed architecture of a virtual prototyping environment [0]. The main components are:

- VR-interface
- presentation unit
- interaction unit
- embedded tools
- VR data model

The VR data model is the description of designed objects as virtual prototypes. It contains information about the objects suitable for the presentation and manipulation in a VR environment.

The presentation unit makes all relevant data visible. This visualization is based on the VR data model, which contains the actual geometry and lighting information generated by the modeling, preparation, and simulation tools. The interaction unit interprets user actions and either changes the viewing parameters or generates logical events for simulation and manipulation. Furthermore, it transmits immediate feedbacks from simulation to the interaction devices.

Integrated simulation tools provide information about product functionalities on-line and allow the virtual prototype respond to a user's input. Modeling tools allow interactive changes of the virtual prototype.

The VR interfaces, together with the presentation and interaction units provide users with the impression of manipulating a real prototype. There are different VR devices available. Depending on the applications, suitable combinations of these VR devices must be chosen.

It should be noted that there is still much research and development work necessary to implement an interface with multi-sensoric realistic feedback.

Additionally, to use existing software and to integrate virtual prototyping into the product development process, following components are required:

- interface between the VR-system and the external tools, respectively
- interface to the product data model base

A virtual prototyping environment does not replace CAD systems. It works upon CAD data. Simulation systems provide additional functional information to a designed object.

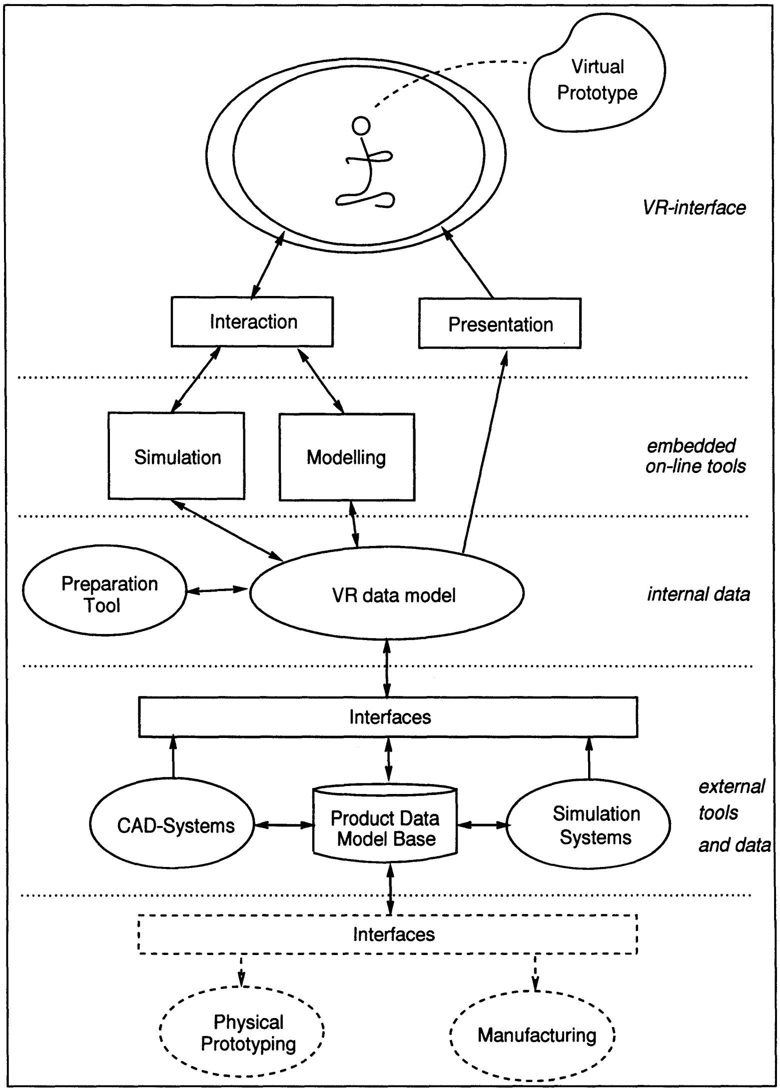

Figure 1 Virtual Prototyping Environment Architecture

In the future, the product data model base will contain the global, integrated product model data. Presently, this data base has to include individual model data from different CAD system vendors with their special data formats. CAD and simulation systems use special data formats which must be converted into the data format of the VR system.

Because CAD systems do not support the specification of materials, textures and other presentation attributes, a preparation tool is needed. Moreover, functional features like product structure, links and some physical properties have to be added.

4 SAMPLE APPLICATIONS

Our current work is focused on the integration of various existing results from the area VR, visualization and simulation to investigate these techniques. Some preliminary implementations of virtual prototyping demonstrates our concept through specific applications. It has provided an illustration of VR-supported design and simulation. Following, four typical application areas are described briefly.

Visual evaluation

Visual evaluation is one of the first application areas of virtual reality. This is also a kind of virtual prototyping, where audio-visual effects are of primary importance. Typically, a walk through is performed in order to get an impression about the spatial relationship of a 3D model. This is especially important in the field of architecture and interior design. In the past, IGD did numerous, high quality presentations together with industrial clients from the furniture industry, city planning, and construction offices.

Furthermore, first examples in the mechanical engineering domain were performed. The data model of the hospital area inside a huge ship has been visually evaluated (see Fig. 2, data provided by the German shipbuilding company Blohm&Voss). Due to highly complex pipeline systems inside a ship, unpermitted pipeline intersections can be constructed very easily. Such intersections have been identified very quickly, with the help of virtual reality walk through techniques.

In all projects we had to deal with "real world data", which means a geometric data base constructed by commercial modeling systems (e.g. AutoCAD, Applicon, ProEngineer). Presently, such systems do not provide sufficient information for virtual prototyping. Always necessary, is a preprocessing of the data base, before it could be passed to the VR system. Important issues are real-time requirements, data consistency, and data enhancement (e.g. specification of additional attributes, like texture, light, etc. for realistic rendering) [0].

Conceptual geometric design

For geometric design, the virtual prototype has to be manipulated in a way, that its form can be changed easily and directly. This implies an underlying data model which allows highly interactive form changes with real-time feedback. The manipulation method must be intuitive to enable a broad user acceptance. The integrated modeling tool does not have to be very powerful, but easy to use.

Fig. 3 presents a prototype system which features interaction techniques for real-time object manipulation. The interaction metaphor is the idea of a potter process. Using a glove a user can point onto the surface of a rotating cube. Real-time collision detection is applied in order to change the form of the cube according to the hand movement. This results in an on-line modification of the geometry. This first example is constructed with triangle meshes. With the experience gathered by this system, future work will concentrate on the integration of free-form-surfaces, like NURBS, and physically-based models (volume, elasticity, etc.).

Conceptual mechanical design

For mechanical design, kinematics is a typical problem often discussed in the conceptual design phase. Additional functional features are, for example, accessibility and assemblibility.

An assembly system has been implemented for research purpose (see Fig. 4) at IGD. With a glove, a user can control a full space cross-hair. Moving the cursor into an object and making a fist grabs this object. It will then follow the movements of the users hand. Open the fist, will release the object at its current location. With this the user is capable to assemble the objects. A precise collision detection with penetration avoidance is applied. When two objects are aligned properly to each other a snapping mechanism will assemble the parts automatically. Due to the lack of force feedback, acoustic signals give additional feedback to the user [0]. Dedicated sounds signalize the object grabbing and release, an object collision, as well as the object snapping.

There are generally two possibilities to evaluate mechanical systems in a VR environment [0] . One possibility is to simulate the mechanisms and assembly off-line, and to show the results in VR. More sophisticated virtual prototyping requires integrated on-line simulation. An example is presented in Fig. 5. During an immersive walk-through the cybernaut can interact with objects of the virtual environment, and these objects expose a realistic (i.e. physically correct) behavior. The lamp in Fig. 5 is represented by an open kinematic chain. It is mounted on the table and can be moved by grabbing parts of it. According to the constraints of the segment joints and the hand movement the on-line simulation results in a correct behavior of the lamp.

Training and prototype evaluation

A broad application field is the domain of training and prototype evaluation. The introduction of a new product on the market can be expedited, when last changes are easily possible and the training of involved people, like maintenance workers can be started before a real product is on hand.

For example, the change of a car engine can be done in a dry test and the generation of its appropriate maintenance manual description can be performed at a very early production level.

The evaluation of a prototype by potential customers can benefit from the VR technology too. No physical prototype mock-up is necessary and so the potential customers of the product (e.g. a new car) can contribute during the whole development process and not only at its final step, when larger changes are not possible anymore.

In contrast to the issues described in the other three application areas, the VR usage here is more oriented towards product user-relationship rather than the product developer-relationship.

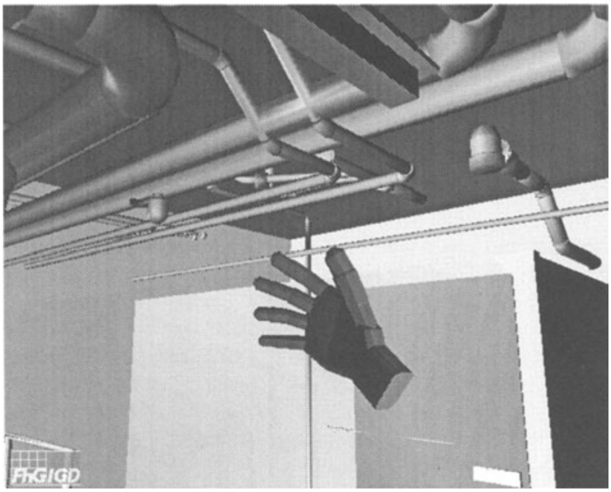

Figure 2 Visual Evaluation of a Ship Unit

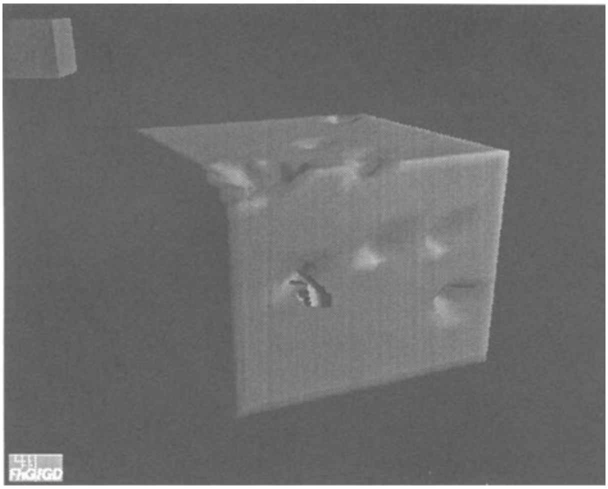

Figure 3 Example of Geometric Design

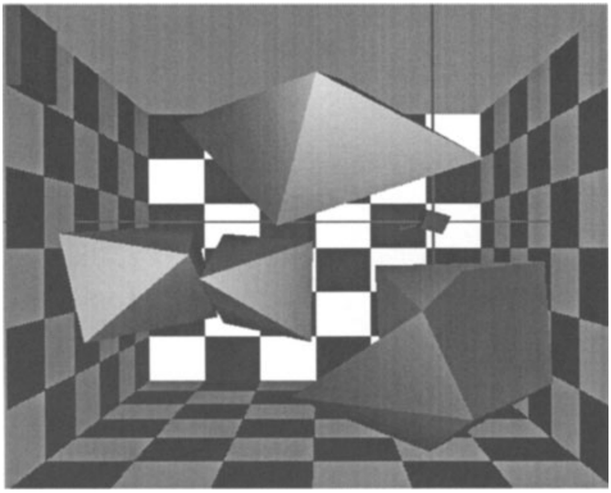

Figure 4 Example for Assembly in VR

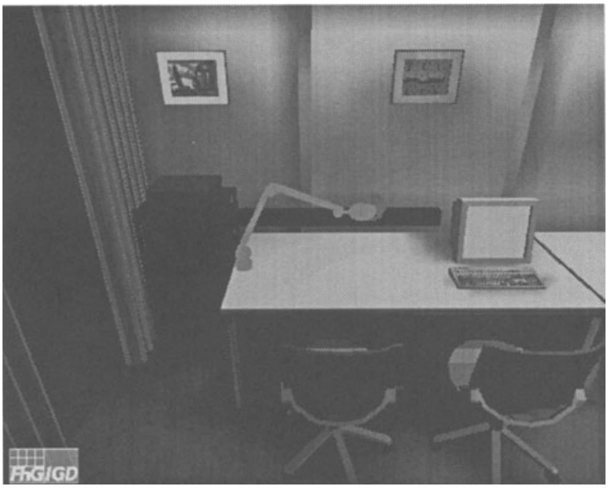

Figure 5 On-line Kinematics Simulation

5 SUMMARY

The main problems of implementing a virtual prototype, using existing software and techniques are:

- the data models of graphics software, specifically VR systems, do not contain attributes for the description of product structure and physical properties
- CAD systems do not provide sufficient information for the presentation and simulation
- the VR interaction methods are not yet realistic enough
- there is no suitable tool for real-time geometrical analysis and physically-based simulations available

Based on the results of our investigations, we will continue to develop more sophisticated embedded simulation tools and to improve the VR interaction methods, especially for direct manipulation of virtual functional prototypes. Evaluation of the existing environment with additional design and engineering applications will be performed in order to develop requirements for additional system components. Furthermore, the integration of virtual prototyping into product development process requires the use of a common product data model and the combination of CSCW (computer supported cooperative work) and VR.

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6 BIOGRAPHY

Fan Dai is a research stuff member and project manager of IGD. He was born in Changde, China 1962. He studied electrical engineering in Saarbrücken, Germany, where he received the Dipl.-Ing. degree. In 1991 he received his Dr.-Ing. degree (PhD) from the Technical University of Darmstadt.

Fan Dai was a researcher with the Interactive Graphics Systems group at the Technical University of Darmstadt from 1985 to 1990. Since 1990, he works with the Fraunhofer Institute for Computer Graphics (IGD) in Darmstadt. His recent work concentrate on dynamic virtual worlds and applications of virtual reality, especially virtual prototyping.

Fan Dai is a member of the IEEE Computer Society. He is also a member of the Association of Chinese Computer Scientists in Germany (GCI, group member of the Chinese Computer Federation), which he chaired from 1990 to 1992.

Wolfgang Felger was born in 1960 in Stockstadt am Rhein (Germany). He received his diploma in computer science from the Technical University of Darmstadt (Germany) in 1987. Since then he has been a staff member at the Fraunhofer Institute for Computer Graphics (IGD), where he received his doctoral degree (PhD) 1995. His research interests focus on scientific visualization and virtual reality. Currently he is technical manager of the virtual reality demonstration centre at Fraunhofer-IGD, with a focus on commercial applications and presentations using virtual reality techniques.

Felger made numerous contributions to international conferences and refereed journals. Furthermore he served as member of the programme committee in virtual reality conferences, organized by EUROGRAPHICS and IEEE.

Martin Göbel was born in 1955, he studied Computer Science at the Technical University of Darmstadt where he received the diploma degree in 1982. From 1982 until 1986 he was research assistant with the Interactive Graphics Systems group at the Technical University of Darmstadt. 1987 he joined the Fraunhofer Gesellschaft. Martin Göbel received the PhD (Dr.-Ing.) in 1990. He is author and editor of 5 books on Graphics Standards and Visualization.

Martin Göbel is head of the Visualization & Simulation Department of IGD. Currently, he is the project manager of the Fraunhofer Demonstration Centre for Virtual Reality in Germany. He chairs a special interest group on VR in Germany and has set up the first Eurographics Workshop on Virtual Environments in September '93 in Barcelona.

Martin Göbel is member of the IEEE Compter Society, EUROGRAPHICs and the German Computer Society (GI). He is actively partipating in EUROGRAPHICS working groups on SCIENTIFIC VISUALIZATION and VIRTUAL ENVIRONMENTS, and the German GI-group on IMAGING & VISUALIZATION.