Using Virtual Environments to Enhance Productivity

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Abstract

Virtual Reality (VR) technologies promise to give people a better understanding of computer data. However, it was not until recently that industrial companies utilize these technologies at a larger scale in order to reduce cost.

The Fraunhofer Society, a government-affiliated research institution in Germany, has established one of Europe's largest Virtual Reality research facilities. Five laboratories (four in Germany, one in the USA) help businesses to introduce VR technologies into their processes. In this paper we give an overview of some recent projects conducted at Fraunhofer labs jointly with companies from the manufacturing and engineering field. We explain which recent trends in technology and user interface research led to this broader adoption of VR. One key factor is the use of CAVE^{tm}-like projection systems instead of head-mounted displays. Finally we argue that VR must and will become just an invisible interface that blends into an existing application and its workflow. Examples of this concept are mainly taken from projects conducted with BMW Corp. and Daimler-Chrysler Corp.

Keywords: virtual reality in manufacturing, projection systems, human-computer interaction, assembly planning.

1. Introduction

Virtual Reality has been around for many years and have without doubt evolved from those early approaches with head-mounted displays (HMD) with an rather limited field-of-view and tracking devices with a resolution of some tens of centimeters. Recent years have brought to us alternative output devices such as CAVE^{tm}-like environments (see Fig. 1 for a similar system developed by Fraunhofer) or stereoscopic wall projection and more precise input devices with optic tracking, for example.

However, it is time to consider - and people from industry keep asking us this question - where there have been real breakthroughs in utilizing VR for serving people's needs, particularly in the industrial domain.

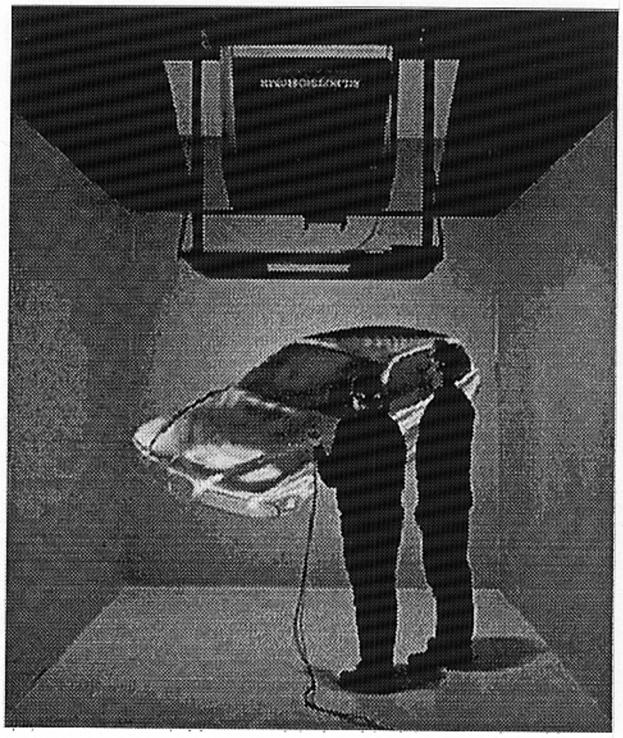

Fig. 1: 4-wall projection system at Fraunhofer IAO

The Fraunhofer Society was established (in 1949) in order to bring new technologies into industry, and this is why its laboratories are particularly interested in establishing "working" systems. Its researchers and engineers have identified 8 major trends in VR research which provide a strong argument [3] for integrating VR technologies into selected industrial domains:

1. Hardware prices drop (as is well-known)
2. VR community grows in Europe. All major European car makers, for instance, have by now in-

[1] This research was conducted at the Fraunhofer Institute for Industrial Engineering IAO, Stuttgart, Germany, http://www.iao.fhg.de

stalled VR laboratories.

3. Less HMDs, more projection systems. Engineers cannot work 8 or more hours in a HMD due to workplace safety and legal regulations. [2]
4. Less gloves, more button devices. The same applies to gloves, human ergonomics teaches us that button devices are more suitable for everyday use. [2]
5. Main fields of application (in Europe): Digital Mock-ups (DMU), virtual prototyping.
6. VR applications are embedded into processes. This contrasts to the stand-alone demos we've seen so far.
7. Integration of simulation into VR applications, such as robotic simulation or autonomous human models.
8. Software is getting more robust and flexible [7].

This list is rather meant to serve as a basis for discussion and may vary from country to country.

Below we illustrate these trends by using three major application domains Fraunhofer has been researching for five or more years, namely assembly planning (section2), car manufacturing (section 3), and VR on the Internet (section 4). In section 5 we give a conclusion.

2. VR in assembly planning

Computer graphics systems for planning of assembly procedures promise to save both cost and time. The Fraunhofer Institute for Industrial Engineering we has been developing a virtual reality assembly planning system with substantial improvements compared to previous systems. These features include "true" real-time 3D visible feedback by integrating fast detection algorithms for collisions between parts, a higher accuracy for describing connections, and an open system architecture which can easily be adapted for application-specific needs.

Despite the progress of automation systems there are quite a few areas left where manual assembly is superior to, say, assembly using robots, e.g. when products change rapidly.

This assembly conducted by workers can be a serious cost factor, especially if parts are assembled inefficiently in terms of time and material use. Moreover, it is clear that arduous or even dangerous assembly procedures can cause serious health damage to the worker.

The developed system is based on virtual reality techniques, that is, manual assembly procedures are visualized by a high-performance graphics workstation in real-time.

Assembly planning engineers can either perform assembly procedures by themselves or observe others conducting them, and immediately evaluate the performance. Furthermore, the system keeps track of various parameters such as time constraints and spatial restrictions and automatically generates a numerical evaluation. This data can then be used to gain additional insight into the simulated process.

2.1. Computer-based assembly simulation

Virtual Reality (VR) systems for evaluation have been introduced for various application domains such as manufacturing, factory automation, architecture, and others [8-10]. Such virtual reality (VR) systems usually consist of three components:

- a spatial input device for measuring head position and orientation, usually via magnetic field trackers,
- a video output device with two independent screens providing independent views for each eye in order to achieve a stereoscopic (i.e., true 3D) impression,
- a real-time graphics workstation for computing new image information according to changes of the viewpoint (indicated by the tracker).

Apart from moving their heads and thus changing their viewpoints users interact with the system via additional input devices such as extra trackers for measuring hand movements or standard devices such as keyboards.

2.2. Virtual assembly planning

For assembly planning we use a set-up as described below. A CyberGlove^{tm} for each hand provides spatial data about the user's hand. The user wears a Head Mounted Display (HMD) and another 3D tracker sensor for measuring head position and orientation.

Tracking input is processed by a Silicon Graphics Onyx supercomputer which then computes suitable video output with respect to the user's viewpoint.

Parts for assembly are extracted from a common CAD database and arranged in front of the user according to their real location at the assembly site. The user can now interactively assemble his parts, for instance by simulating screwing, welding, riveting, and others. Tools for these operations are also simulated visually.

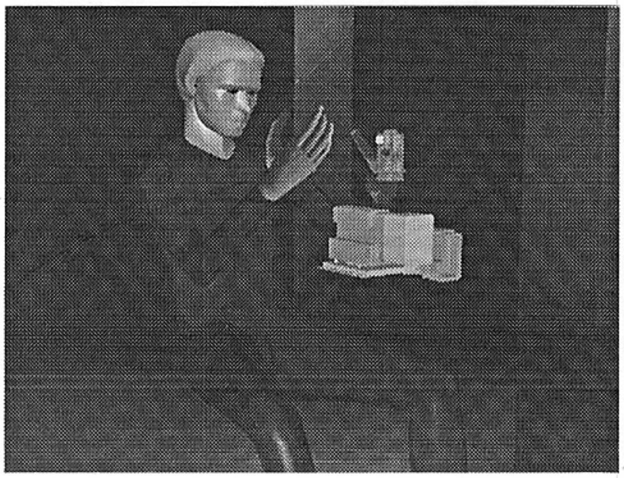

Fig. 2: assembling electric appliances: observer's perspective

Feedback is essential for a realistic simulation. So we included a virtual human model called *Virtual Anthropos*^{tm} which was also developed at our laboratory. Users can now see themselves when assembling (fig. 2) and thus correct obvious mistakes. Moreover, the computer is powerful enough to compute images for one or more additional viewpoints for persons observing the person at work on an extra screen (fig. 3). They can change their viewpoint freely during the assembly process in order to, for instance, zoom in during critical phases.

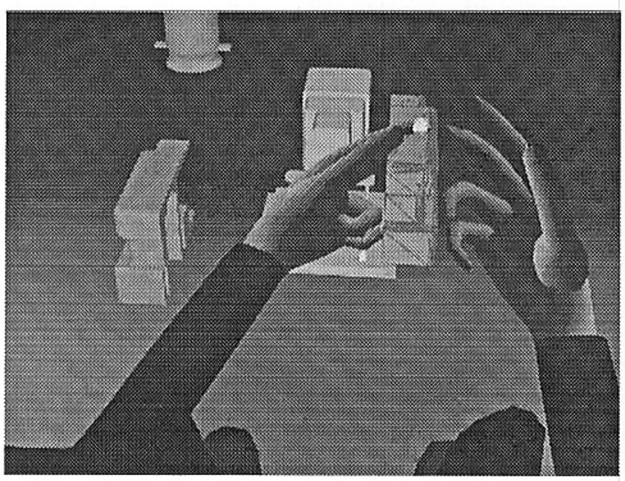

Fig. 3: worker's perspective

The system automatically tests for feasibility of operations and provides suitable feedback. For instance, parts colliding with each other will not be allowed to pass through each other. When touching each other they briefly change their colors and an acoustic signal is given. This is to indicate the collision to the operator who, at least not in the current implementation, does not get haptic feedback about the collision. This is particularly useful when parts do not easily fit but have to be rotated or even twisted in order to be connected.

While keeping track of user actions the system computes various data for later evaluation. First, an assembly precedence graph is generated as output. It contains data about the order of assembly, the ways of connection between parts, and their respective time and cost requirements. By comparing graphs taken from several sessions the most suitable assembly graph can be selected and then applied in the production environment.

In addition, if a specific order for assembling parts is given in advance, the system can generate a protocol of the mistakes made even if they happen in a speed invisible to the untrained human observer.

Since Virtual Anthropos is based on an ergonomic motion model certain statements can be made on the "healthiness" of the movements performed by the user.

2.3. Outcome

In this research we have shown how virtual reality simulation can greatly improve the efficiency of manual assembly procedures [4-6]. We introduced the *Virtual Anthropos*^{tm} virtual human simulator which are key components for our assembly system. Both are undergoing continuous improvement, for instance for improving the accuracy of collisions between man/part and part/part. Furthermore we are integrating other types of tracking devices which do not base on magnetic fields but optical pattern recognition using video.

3. VR improves productivity in the car manufacturing industry

Like other major car makers all over the world, BMW Corporation, a German car manufacturer, has adopted concurrent engineering techniques for new products in both the design and systems engineering field. This approach was chosen since the largest part of the development cost of a new car is allocated in the concept definition phase and errors made in this period cause extremely high cost at a later stage [Reuding98]. That is, specialist knowledge from downstream tasks is introduced by a large number of experts, particularly in the CAD and CAE application domains which are widely in use.

In order to provide a communication platform for supporting concurrent engineering of a large team, BMW Corporation and Fraunhofer jointly developed a VR application for the evaluation of CAD data in a virtual environment. For internal reasons, the development process of sheet metal forming machines was chosen as a testbed for the use of VR, but the results of this research can be expected to be introduced in other application fields at BMW in the near future.

Each of the engineers involved in the given field has his/her own technical background. The machines are very complex mechanical, pneumatic, and hydraulic engines which have to operate during the whole expected lifetime of a car. The cost for these metal forming tools is very high and it can be estimated that a better time performance when developing such tools leads to a significant time reduction for the entire car development process.

The CAD data used for this application represent the current construction state of a new car model and can be exported for evaluation tasks into a virtual environment. The VR environment consists of

- a rear projection system with a 1-wall projection surface (3 m x 2.2 m),
- a tracking system for one person,
- a Silicon Graphics Onyx2 IR with 2 RM5 for displaying a stereoscopic image for this person,
- CrystalEyes^{tm} LCD shutter glasses,
- ERCO light system.

Online database retrieval was used to get the car data from the CAD system into the VR application. Major VR tasks to be performed included:

- switching objects from hidden to visible
- virtual cut through objects
- moving and rotating virtual objects
- marking parts
- virtual ruler for measurement tasks

Six or more engineers had to work together. At any time each of them has to know exactly what the others are talking about. In a virtual environment with just only one tracked person this led to the development of a 2-hand interaction device. The person with the tracked glasses can interact with one and the other person(s) can point with the other device. As a virtual representation of the interaction devices was introduced, it showed everyone the exact position of the part currently under discussion.

The first approach when designing these interaction devices was to develop two small tubes with buttons and a built-in tracking sensor, rather similar to the wand devices widely in use. The buttons were sampled periodically and the status change was transmitted to the host system. The buttons in the left hand were used for grabbing, moving, and turning objects. When the buttons were pressed the grabbed object moved according to the tracked direction.

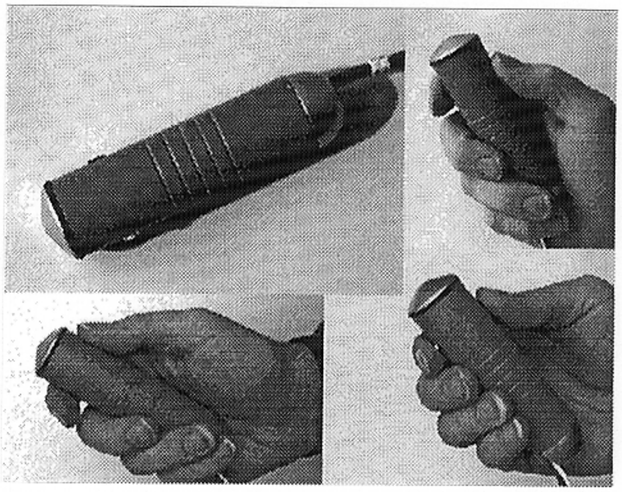

Fig. 4: Interaction devices

The right hand device was used for the cutting plane. When one of the buttons was pressed the tracking sensor output was connected with the cutting plane and moved accordingly. To make interaction easier, a grid snapping function was added. When the angle between the current plane and the x/y or x/z plane (resp.) was near zero the plane was automatically snapped to the respective plane.

The system was installed at a BMW development facility and has been in use for more than 5 months since then. BMW has reported a considerable performance and cost improvement in the design process, though numeric evaluation data of this is not yet available.

4. VR enhances collaboration on the Internet

In the Virtasyo (Virtual Architectural System Online) project Fraunhofer and Bertelsmann Corp., a large European Media Corporation jointly developed an Internet-based VR application where architects and their clients can design 3D rooms and furnish them by choosing from a 3D online database.

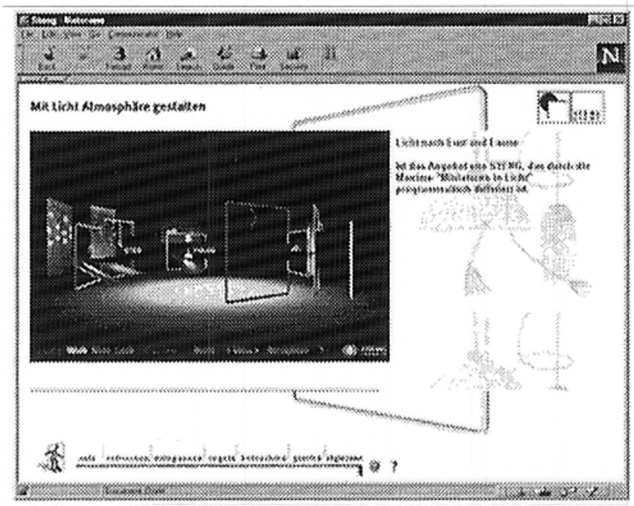

Fig. 5: Virtasyo example room

Users can configure details of the pieces of furniture they include such as color and shape by choosing from a variant database. The 3D representation is updated automatically, and users can (non-immersively) interact with both the rooms and their furniture, e.g. by moving the pieces to new locations. Users get an unique impression on how the building to be furnished will look like and, even more importantly, can include new components via the internet. So far, the system contains products of seven German furniture manufacturers.

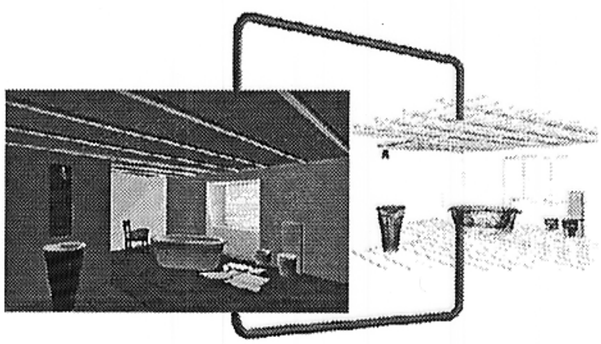

Fig. 5: Virtasyo user Interface (partly shown)

Subsequently, Fraunhofer currently creates a car configurator for MCC Micro Compact Car Corp., a subsidiary of Daimler-Chrysler and Swatch Corp. Similarly to Virtasyo, users can walk through an Internet-based model of a MCC car and change features according to their taste. Both applications were implemented using the VRML and Java Internet standards [13, 23].

5. Conclusion and outlook

In this paper we gave an overview on novel projects within the Fraunhofer Society which are relevant for our argument that VR is getting its way into industry. Only if companies recognize the true value of VR, namely its potential to enhance the productivity of designers, engineers, salespersons, and other business-to-business communicators, virtual reality will have a breakthrough impact on applications. If this is the case, we conclude, virtual reality will no longer be the key technology of an application but will rather "evaporate" in order to become an user interface technology. Our vision is that VR will be included into applications as easily as today's UI widgets and libraries such as Motif^{tm} and MS Windows^{tm} are added to current desktop applications.

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