

# Virtual Reality: Computational Modeling and Simulation for Industry

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## ABSTRACT

This paper outlines the core technologies which underline the principle of virtual reality and the way it is being applied today in industry. In a more general sense virtual reality provides a true 3D interface to a range of computer applications. The essence of virtual reality is immersion, which is the ability to immerse the computer user in a computer generated experience, as an active participant, as opposed to a passive viewer. Hence this paper provides an introduction into the methodology of virtual reality, including its historical background, as well as some basic taxonomy, that are helpful defining the elements of a virtual reality, that are used to create immersive and interactive experience. Moreover this paper report about industrial case study examples of Virtual Reality as an advanced computational method in modeling and simulation of complex dynamic systems.

## 1 INTRODUCTION

Virtual reality (VR) can be described as a synthetic 3D computer generated universe that is a perceived as the real universe. The key technologies behind virtual reality systems (VRS) and virtual environmental systems (VES) are

- Real-time computer graphics
- Colour displays
- Advanced software

Computer graphics techniques have been successfully applied for creating synthetic images, necessary for virtual reality and virtual environments. Creating an image, using computer graphics techniques are used to store 3D objects as geometric descriptions, which can then be converted into an image by specific information of the object, such as colour, position, and orientation in space, and from what location it is to be viewed.

Due to this possibilities computer graphics is now well established and developed as a standard for Computer Aided Design (CAD) systems. With a CAD system e.g. one can render perspective views of the scene under development. The success of CAD has been greatly influenced by the advances of computer architecture due to the microminiaturization of computer chips, and the instruction level parallelism of computer architectures, realized as pipelined instruction processing and superscalar instruction handling in modern microprocessors, that allow to build low cost graphic workstations that can support the real-time intensive manipulation of large graphic databases.

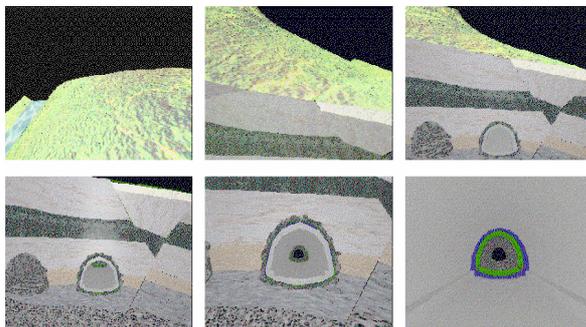
Real-time computer graphics techniques allow the user to react within the time frame of the application domain, which finally results in a more advanced man machine interface, which is the whole rationale for virtual reality systems and virtual environments. This has been possible by overcoming the delays that occur e.g., while rendering of very large database, since the computer power increase and henceforth the graphics performance, due to the instruction level parallelism. An unpipelined processor is characterized by the cycle time and the execution times of the instructions. In case of pipelined execution, instructions processing is interleaved in the pipeline rather than performed sequentially as in non-pipelined processors. Defining the performance of pipeline processing the performance potential of the pipeline equals the number of independent instructions which can be executed in a unit interval of time.

Colour displays are used for displaying the views of the virtual reality and virtual environment universe to provide a visual sensation of the objects from the real-world domain (industrial physical application) into the virtual domain. The colour displays are of great variety, such as monitors fixed to the windows of the simulator cockpit for visual sensation of flying in a flight simulator (see Figure 3), or Head Mounted Displays

which visually isolates the user from the real world. A head mounted display (HMD) can provide the left and right eye with two separate images that include parallax differences, which supplies the users eyes with a stereoscopic view of the computer generated world, which is a realistic stereoscopic sensation.

Advanced software tools are used to support the real-time interactive manipulation of large graphic databases, which can be used to create a virtual environment, that can be anything from 3D objects to abstract data bases. Moreover, 3D modelling and simulation tools are part of the advanced software tools. Hence, a 3D model can be rendered with an illumination level simulating any time of the day, or using OpenGL, a quasi standard for 3D modelling and visualization, one can create geometrical bodies of every shape and size for simulating the different views of geotechnical and geophysical parameters e.g. of a tunnel scenario, as shown in Figures. 1 and 2, which can be moved in size in real time, using advanced simulation software tools, such as NURBS or the MBA algorithm. The image realism can be improved by incorporating real-world textures, shadows, and complex surfaces, etc.

Example 1: Based on OpenGL, a quasi standard for 3D modeling and visualization, one can create geometrical bodies of every shape and size and move them in real time, within a virtual reality simulator, as shown in Figure 1, that shows the sequence of a “flight through a tunnel”. Figure 1 top line from left to right: overall scenic view of the landscape; scenic view and different geological structures; scenic view, different geological structures and tunnel inlets. Figure 1 bottom line from left to right: different geological structures and tunnel portals; different geological structures at the tunnel portal; scenario inside the tunnel with the end of the tube in front of the view.

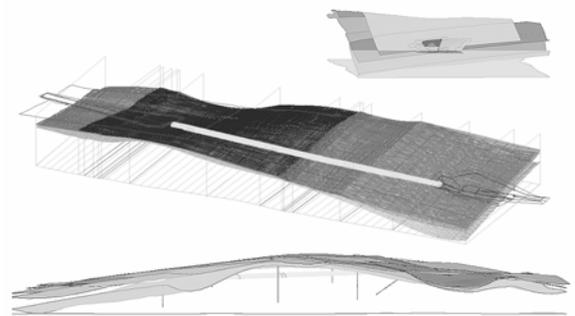


**Fig. 1.** Virtual reality tunnel simulation scenario

Due to intuitive interaction with the virtual reality techniques new scenic presentations are possible, as shown in Figures. 1 and 2, which offers concepts for

modelling and simulation of complex real-world systems with parameterized or non parameterized topologies within a unique framework. This results in rapid prototyping based on flexible modelling tools with concepts for geometry, motion, control, as well as virtual reality components like images, textures, shadowing, rendering, animation, multimedia, etc.

The technical complexity associated with developments in the virtual universe requires the use of metric values, which can then be converted into several important factors that relate to the metric values themselves, especially metric dimensionality, metric attributes, metric types, etc.



**Fig. 2.** 3D model of the virtual reality tunnel simulation scenario of Figure 1.

Top: General 3D NURBS model view  
 Middle: 3D NURBS model view of the tunnel and the geological structure with tunnel portals  
 Bottom: 3D Geological formation model view

The primary goal using virtual reality is to unite the power and flexibility of virtual reality methodology with the insight of ubiquitous computing which can be stated as computation in space and time, based on:

- Image processing, which contains the two sub-topics of image acquisition and image analysis, that are necessary to produce 3D information to generate a useful representation of the environment
- Computer graphic and visualization, which is necessary for modelling virtual environments, creating stereo visions and rendering images, whereby the time to render an image has always been a major issue of computer graphics, especially with animated sequences
- Synthetic scene generation
- 3D modelling based on splines, NURBS and other innovative algorithms such as V-NURBS or VT-NURBS

Henceforth very new scenic presentations are possible, containing branch specific elements and knowledge in

the respective application domain. Moreover the effect of immersion, which means the realization of space depth, allows the user, a fast adaptation to processes in space and time. Virtual reality offer a concept for modelling complex systems with parametric as well as nonparametric topology within a unique frame. This results in rapid prototyping, based on flexible virtual reality modelling tools with concepts for geometry, motion, control, as well as virtual reality components like images, textures, voice, animation, multimedia, video, etc.

The technical complexity associated with developments in the virtual reality domain require for the introduction of characteristics of metric values. In the development of utility metric values, several important factors that relate to the metric values itself must be considered. These areas that are

- Metric dimensionality
- Metric attributes
- Metric types.

A very easy and straightforward approach for realisation of metric valuated dimensions could be found using one-dimensional scaling. Methods of one-dimensional scaling, however, are generally applied only in those cases where there is good reason to believe that one dimension is sufficient.

But metric valuated accuracy and presentation fidelity leading for a multidimensional scale. A multidimensional scale is necessary for an adequate images quality description, if additional information would probably be required. Therefore a multi-dimensional scale must be developed.

Metric valuated attributes are actual quality parameters measured along each quality dimensions, which are:

- Realism: defined as degree of fidelity of representations compared with truth. The degree of realism vary from task to task. To enhance levels of realism often certain kinds of standard features and effects are used.
- Interpretability: corresponds to the level of resolution, which coarsely could be defined as the smallest feature that can be distinguished in an image. This, in turn, directly impacts the level of information that can be interpreted from an image.
- Accuracy: deals with the correctness of objects represented in the scene, and their correct locations. Accuracy depends of source materials used, like geometry derived from imagery, physical models,

etc. as well as the fidelity of the transformations used.

There are a number of possible metric valuated types that could be used for the dimensions of a quality assessment metric. These types are [Yachik, 1998]:

- Criteria based ( on a textual scale which define the levels of the scale)
- Image based (on a synthetic scene where a rating is assigned by identifying the standard image having a subjective quality that is closest to that being rated)
- Physical parametric based (on measured values based on integrated power spectrum, or mensuration error, etc.)

Methodology developers realized that logical constraints or axioms are necessary in order to enhance with mathematical meanings, like [Yachik, 1998]:

- Monotonic  $\Rightarrow$  as items increase in values, the scale number increases
- Continuity  $\Rightarrow$  intermediate scale values have meaning
- Transitivity  $\Rightarrow$  if item a > item b > item c; then item a > item c.

Several scales can be developed that satisfy these axioms to various degrees.

Virtual Reality is a natural domain for collaborative activities because VR allow users doing things they normally cannot do in reality, e.g. being within a molecule, being inside the combustion chamber of an automobile engine, walking through a tunnel in „outer space“ etc.

The big challenge of virtual reality techniques is that it takes us one step closer to virtual objects by making us part of the virtual domain. Computer graphics techniques used in the virtual reality systems of today providing visual images of the virtual universe, but the systems of tomorrow will also create acoustic images of the virtual universe, which can be introduced as sonification or the 5-th dimension of the virtual reality technique – while time is the 4-th dimension – that can stimulate recognizing sounds in virtual environments. One could imagine that more modalities of user interaction, such as tactile and haptic modalities for touching and feeling of virtual objects, can complete the sensation of illusion in virtual worlds, which can be introduced as the 6-th and higher dimension of virtual reality techniques. Moreover, smelling and tasting may also become imaginable in virtual environments, en-

hancing the order of dimension. Henceforth multi-modality, that cover the sensation in virtual worlds, has become one of the major topics in the design of virtual environments. The benefits of the technique of virtual reality are manifold, that is why this technique is so vital to many different application domains, ranging from applications in the automotive and avionics industry, applications in the more advanced military industry, as well as molecular and medical topics, catastrophic management, education and training, etc., and ends up into the different academic research domains. Based on features offered through computer graphics techniques, meaning visualization of highly realistic models, and through the integration of real-time computing, virtual reality enables the user to move around in virtual environments, such as walking in the environment of a tunnel or walking through the through a tunnel, as shown in Figure 1, or to acquire flying skills without involving real airplanes and airports, as realized in virtual training environments for pilots, as shown in Figure 3, etc.

Based on the spatial and temporal geometric description, which can then be converted into an image by specifying the respective information behind, virtual reality techniques can be used as the basic concept for virtual-world simulation, as well as for analysis and prognosis of complex processes in virtual worlds.

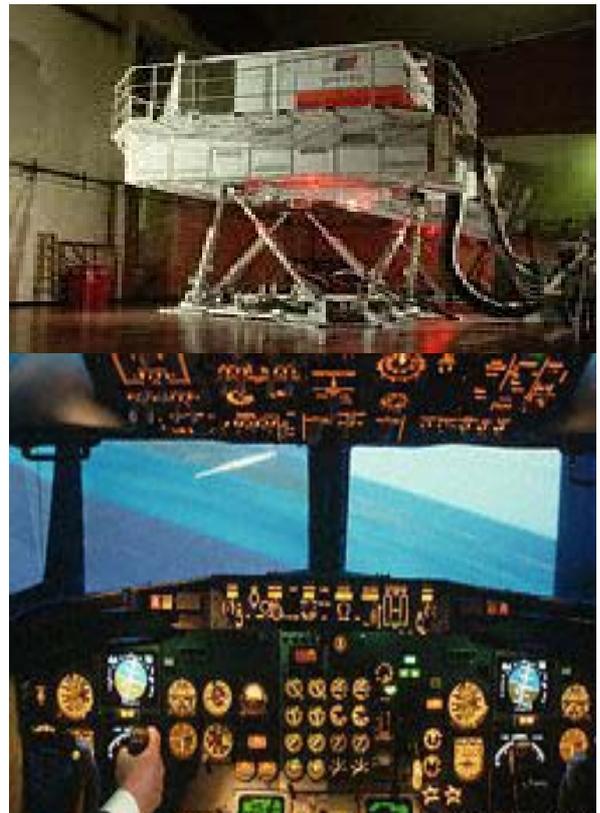
Furthermore, underlying databases in virtual-environments offer the ability to store and retrieve heterogeneous and huge amounts of data for modelling virtual worlds. Hence, virtual reality can be seen as a specific type of a real-time embedded system combining different technological approaches that are integrated within one environmental solution.

In the case of a flight simulator, as shown in Figure 3, the computer graphics techniques are used to create a perspective view of a 3D virtual world, and the view of this world is determined by the orientation of the simulated aircraft. Simulating the complex behaviour of the aircraft requires a sophisticated modelling technique and embedding of several real-time systems, such as engines, hydraulics, flight dynamics, instruments, navigation, etc., as well as weather conditions, and so on, which are components and modes of the flight simulators virtual-environment. The information necessary to feed the flight simulator with real-world data are available from the databases of the aircraft manufacturer and the manufacturer of the aero engines. They describe the dynamic behaviour of the aircraft when taxiing on the ground, or flying in the air, or engine temperature and fuel burn rates, etc. The flight models used in the flight simulator are based on the data obtained from the manufacturer as well as the

data describing the flight controls to simulate the behaviour of the airplane under regular as well as under non-regular flight conditions.

During flight simulation, the pilot – as well as the co-pilot – sit inside a replica cockpit and gaze through the forward-facing and side-facing windows, which are 200° panoramic displays reflecting the computer-generated graphical virtual universe. The flight simulator creates a realistic sensation of being in a real-world plane flying over some 3D landscape, as shown in Figure 3. But today, the flight- simulator panoramic displays do not contain stereoscopic information, the fact that the images are collimated to appear as though they are located at infinity creates a strong sense of being immersed in a 3D world.

Furthermore, immersion can be enhanced by allowing the users head movements to control the gaze direction of the synthetic images that provides the users brain with motion-parallax information to complement other cortical pathways of the visual cues in the brain. This requires tracking the users head in real time, and if the users head movements are not synchronized with the images, the result will be disturbing.



**Fig. 3.** Hydromechatronic flight simulator mock up (top) and cockpit view from inside the flight simulator (bottom)

When visually immersed within a virtual environment there is a natural inquisitive temptation to reach out and touch virtual objects as part of interaction possibilities in the virtual universe, which is impossible, as there is nothing to touch and to feel, when dealing with virtual objects. But, the users sense of immersion can be greatly enhanced by embedding tactile feedback mechanisms in the virtual environment. Embedding tactile feedback needs some specific hardware components, such as data gloves, which enable the user to grasp or to sense real-time hand gestures. Hence data gloves will provide a simple form of touch-and-feel stimulus where small pads along the fingers stimulate a touching and feeling sensation. Thus, if a collision is detected between the users virtual hand – the data glove – and a virtual object, the data glove is activated to stimulate the touch and feel condition. However, the user may not be suddenly aware of the objects mass, as there is no mechanism for engaging the users arm muscles. Therefore, it is necessary to transmit forces from the virtual domain to the user interface, meaning there is a need for embedding articulated manipulators in the virtual environment that could create such forces.

In general for virtual space applications the following main components are available:

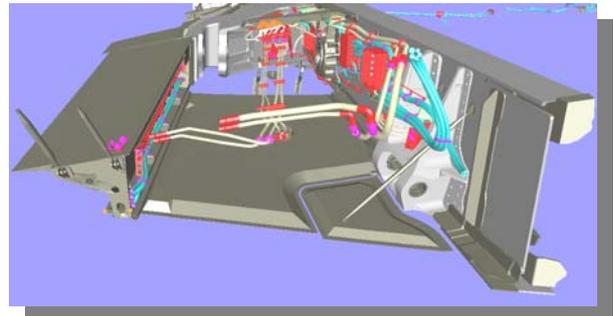
- Space ball and cyber gloves for tactile interaction in virtual space
- In-transparent head mounted devices for visual interaction in virtual space; transparent head mounted devices are used for augmented reality application
- 3D geometric body creation and motion methodology for “virtual space feeling” capability
- 3D visual interactive components for definition, manipulation, animation and performance analysis of geometric bodies
- Object oriented data base for efficient data management
- Objects organization into single-inheritance hierarchies for virtual reality system transparency. When objects are created, they inherit the properties and verbs of their ancestors. Additional verbs and properties as well as specializations of inherited components may be defined to give the new object its unique behavior and appearance
- Computing hardware for computing in space and time

There are many advantages of working in the virtual domain, such as:

- Accuracy due to subject specification: means real world models can be built with great accuracy as they are based upon CAD data of the real objects
- Flexibility: means building virtual representations of anything as well as interacting with this representation due to the virtual reality front ends
- Animated features: means animation of sequences, objects, etc., in space and time

Example 2: Combining these aspects for real-time simulation in virtual environments can be based on the integration of the overall information, but only a few approaches maintain this problem and have been developed like cave automatic virtual-environments, or digital mock up (DMU) in the avionic industry, shown in Figures. 4 and 5, allowing the user a real-time interaction that is not only restricted to the 3D model itself, it also is parameterized, which could lead to a better framework for real-world system analysis, such as

- Statistic and cinematic interference tests
- Development of new methods for DMU application
- Investigation of applicability of new technologies within the virtual product design process



**Fig. 4.** Digital mock up (DMU) of a air planes wing



**Fig. 5.** Digital mock up (DMU) of an air plane wing showing the application of virtual reality to simulate the possibility of a maintenance procedure at the air planes wing

In contrast to Virtual Reality (VR) Augmented Reality (AR) deals with the combination of real and virtual environments. The AR system supports the user, based on semi-transparent output devices, with the relevant computer based information. This means that the images users will see on their AR device show the geometry dependent right perspective in correlation to the real world scenario.

## 2 HISTORICAL DEVELOPMENT OF VIRTUAL REALITY

Like most technologies, Virtual Reality (VR) did not suddenly appear. It emerged in the public domain after a long period of research and development in Industrial, military and academic laboratories. The emergence of VR was closely related to the maturity of other technologies such as real-time computer systems, computer graphics, displays, fibre optics and 3D tracking. When each of these technologies could provide its own individual input, a crude VR working system appeared. But this was a very long way with inventions and discovery. The foundations of today's important technologies used for VR goes back into the twentieth century. The scientific landmarks of which shows the following:

- 1944: Harvard Computation Laboratory completed their automatic general-purpose digital computer
- 1954: Cinerama was invented with 3 cinema screens
- 1956: Morton Heilig invented the Sensorama, a CRT based binocular headgear
- 1960: The Boeing Corporation coined the term Computer Graphics
- 1963: Ivan Sutherland submitted his PhD thesis "SKETCHPAD: A man-machine graphical communication system"
- 1966: NASA commence with the development of a flight simulator
- 1968: Ivan Sutherland published "A Head-mounted 3D Display"
- 1977: Dan Sandin and Richard Sayre invented a Bend-Sensing Glove
- 1981: Tom Furness developed the Virtual Cockpit
- 1984: William Gibson wrote about Cyberspace in the book Neuromancer
- 1989: Jaron Lanier coined the term Virtual Reality
- 1990: Fred Brooks developed the force feedback
- 1991: After founding in 1990, several industries selling their first VR System
- 1993: SGI announced the Reality Engine
- 1994: The Virtual reality was founded

## 3 VIRTUAL REALITY TAXONOMY

Applying the virtual reality methodology to the industrial domain could be stated as combining distributed virtual environments, in order to support collaboration among distance team members developing plans and procedures, doing measurements and data processing, in order to attempt to manage new investigations and organizations collaboratively, as it is needed in global as well as international project development.

One of the most interesting new paradigms in virtual reality methodology in this domain is that 3D representations are not only the lonely possibility of a setting.

Many virtual space applications in today's industry, if not already now, will in future make use of specific graphics. The virtual reality will be visualized in space, which means in terms of 3D, and due to dynamic aspects in time. People that are work in VR projects are able to interact image based within space and time, e.g. fighting a plane, inspecting car crash behavior, interacting with other participants through a graphical user interface, etc. The interweaving of functionality, distribution, efficiency, and openness aspects is very noticeable in computer graphics. The virtual space is graphically visualized flamboyance and for the most part the people work in the outer space application domain will see the same images. In real industrial projects, irrespective of the number of participants, a change of state in the virtual space needs to be communicated to all invented in the project.

Therefore, for virtual space applications, 3D multiuser virtual reality tools have been developed for industrial applications, consisting of the following main components:

- space ball and cyber gloves for tactile interaction in virtual space
- head mounted devices for visual interaction in virtual space
- 3D geometric body creation and motion methodology for "virtual space feeling" capability
- 3D visual interactive system for specification, manipulation, animation and performance analysis of industrial bodies
- object-relational oriented data base for efficient data management in virtual reality applications
- computer hardware for the power of computing in space and time
- objects organization into single-inheritance hierarchies for virtual reality system transparency

When objects are created, they inherit the properties and verbs of their ancestors. Additional verbs and properties as well as specializations of inherited components may be defined to give the new object its unique behavior and appearance.

The presentation of process states is of importance, which has to be realized time dependent, combining real scenarios as well as virtual scenarios, in order to find out optimal geometries, based on a specific mathematical annotation, that are Non Uniform Rational B-Splines (NURBS).

This special kind of B-spline representation is based on a grid of defining points  $P_{i,j}$ , which is approximated through bi-cubic parameterized analytical functions.

$$P_{i,j} = \left\{ \begin{array}{cccc} p_{1,1} & p_{1,2} & \cdots & p_{1,n} \\ p_{2,1} & p_{2,2} & \cdots & p_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m,1} & p_{m,2} & \cdots & p_{m,n} \end{array} \right\}, p_{i,j} = (x, y, z)$$

$$S(u, v) = \frac{\sum_{i=0}^n \sum_{j=0}^m N_{i,p}(u) N_{j,q}(v) w_{i,j} P_{i,j}}{\sum_{i=0}^n \sum_{j=0}^m N_{i,p}(u) N_{j,q}(v) w_{i,j}}$$

$$0 \leq u, v \leq 1$$

This method allows to calculate the resulting surface or curve points by varying two (surface) or one (curve) parameter values  $u$  and  $v$  of the interval  $[0,1]$ , respectively, and evaluating the corresponding B-Spline basis function  $N_{i,p}$ .

$$N_{i,0}(u) = \begin{cases} 1 & \text{if } u_i \leq u \leq u_{i+1} \\ 0 & \text{otherwise} \end{cases},$$

$$N_{i,p}(u) = \frac{u - u_i}{u_{i+p} - u_i} N_{i,p-1}(u) + \frac{u_{i+p+1} - u}{u_{i+p+1} - u_{i+1}} N_{i+1,p-1}(u)$$

$$U = \{u_0, \dots, u_m\}, u_i \leq u_{i+1}, V \text{ analogous}$$

The parameter values  $u$  and  $v$  can be chosen continuously; the resulting object is mathematically defined in any point thus showing no irregularities or breaks

There are several parameters that approximate given points and thus adapting the view of the described object, and interpolation of all points can be achieved.

Firstly, the polynomial order describes the curvature of the resulting surface or curve, representing the mathematical function at a higher level of flexibility. Secondly, the defined points can be weighted in accordance to their dominance with respect to other control points. Hence a higher weighted point influences the direction of the surface or curve more than a lower weighted one. Furthermore, knot vectors  $U$  and  $V$  define the local or global influence of control points, so that every calculated point is defined by smaller or greater arrays of points, resulting in local or global deformations, respectively, as shown in Figure 6.

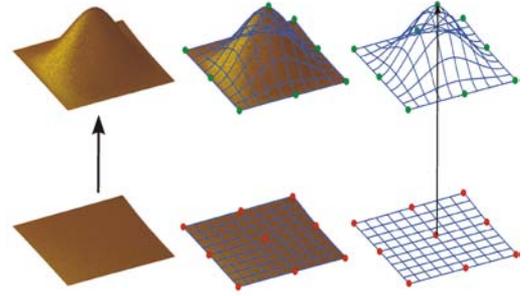


Fig. 6. Modelling and modification of a NURBS surface

NURBS are easy to use, as modelling and especially modifying is achieved by means of control points movement, allowing the user to adjust the object simply by pulling or pushing the respective control points.

Based on these concepts a mathematical methodology is available that allows to interpolate given sets of points, for example the results of scanned data of the human face surface measurements, as shown in Figure 7.

Using multiple levels of surface morphing, this multi level B-spline approximation (MBA) adjusts a predefined surface, i.e. a flat square or a cylinder. Constraints like curvature or direction at special points can be given and are evaluated by the algorithm.

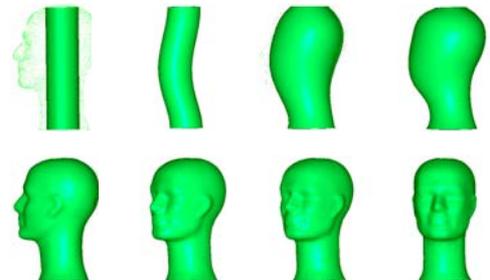


Fig. 7. Morphing, by using multi level B-splines approximation

#### 4 VIRTUAL REALITY SYSTEMS IN INDUSTRY

One of the reasons that VR has attracted so much interest in the military and in the industry is that it offers enormous benefits to so many different application areas.

VR systems firstly have been applied at the US Air Forces Armstrong Medical Research Laboratories developing an advanced fighter cockpit which later has been adapted by the avionic industry as flight simulator for pilot training (see Figure 3) and used by commercial airlines and the military for over twenty years. They are used for training pilots in developing new skills in handling aircraft under usual and unusual operating conditions, and discovering the flight characteristics of a new aircraft.

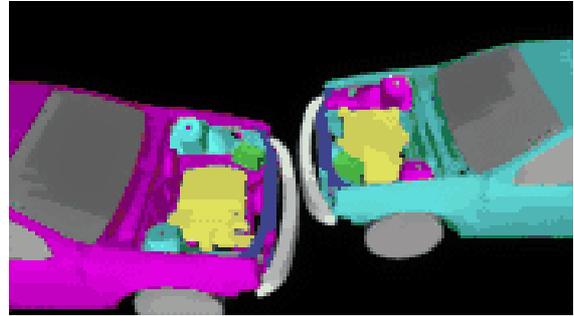
Other applications deals with operations in hazardous or remote environments, where workers could benefit from the use of VR-mediated teleoperation. People working in radioactive, toxic or space environments could be relocated to the safety of a VR environment where they could handle any hazardous materials without any real danger. But telepresence needs further development in tactile and haptic feedback to be truly useful. Today one may find high sophisticated Industrial VR teleoperation applications in the field of nanoscience based on force feedback manipulation, as shown in Figure 8.



**Fig. 8.** Force feedback manipulator

Many areas of design in industry are inherently 3D. Example 3: The design of a car shape needs 3D support while the designer looks for sweeping curves and good aesthetics from every possible view, as well as

placing parts and sub-systems within the car, as shown in Figure 9.



**Fig. 9.** VR design in industry (for details see text)

Moreover the expensive physical car crash tests, as shown in Figure 10, have been adapted for use in a virtual car crash simulation environment. This requires the mathematical description of the procedures, a task which is not trivial. In general the real problems arise in designing an interface where such behaviours can be associated with arbitrary geometric databases.



**Fig. 10.** Physical car crash test

Furthermore, shared VR environments will allow possibly remote workers to collaborate on tasks. The VR environment can also provide additional support for the collaboration of industrial designer teams. For

specific application areas, such as land exploration or architecture, caves and domes, as shown in Figure 11, become the most important virtual reality environment.



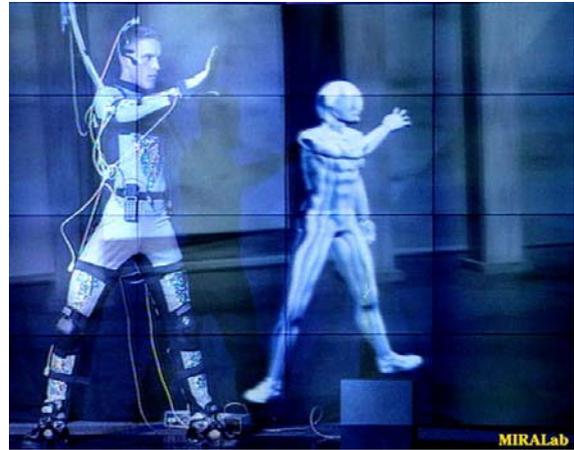
**Fig. 11.** Domes and caves as VR environments (for details see text)

More and more gesture driven interaction as a human factor in virtual environments become of importance. The reason behind is very simple., because if the VR environment is designed to follow some metaphor of interaction in space, and the objects in the environment have behaviour similar to objects in the real world, it can be very intuitive for the user to visit and experience this environments.

One possibility behind gesture driven interaction in VR environments is the possibility using avatars with hand gesture to communicate with deaf people.

The MIRALab at Genova, Switzerland, chaired by Prof. Nadja Thälmann, is one of the pioneers in gesture driven interaction. They build individualized wal-

king models, walking along an arbitrary path, fashion shows, virtual tennis games, and cyber dancing, as shown in Figure 13.



**Fig. 12.** Cyberdance in VR

Moreover VR has become part of entertainment. Current equipment in this domain is used for role playing games. It consists of a number of units networked together in which a team of players stand to play on this roles.

Summarizing the above mentioned VR environments with its specific application In general VR application in industry can be found in:

- Engineering:
  - Aero engine design: where engines are designed to withstand incredible forces during operation, and must function in all types of whether, and over incredible ranges of temperature and atmospheric conditions
  - Submarine design: where VR is used to investigate maintenance and ergonomic issues, as well as model human figures to evaluate how real humans cope with working in the confined spaces associated with submarines
  - Industrial concept design: where collaborative work is used to interact with virtual car concepts, and how such designs can be evaluated for functional correctness, easy assembly and even maintainability
  - Architecture: where VR is a technological progression that brings architects closer to their visual designs
- Entertainment:
  - Computer animation
  - Games systems

- Science:
  - Visualization of electrical fields
  - Molecular modelling
  - Telepresence
- Training:
  - Fire service
  - Flight simulation (see Figure 3)
  - Medicine
  - Military training (see Figure 13)
  - Nuclear industry
  - Accident simulator (see Figure 14)



Fig. 13. Military training using VR



Fig. 14. Accident simulator using VR

## 5 CONCLUSIONS

If we look at the relationships between computers and humans over the past 20 years, we find out that a merge occur bringing both world closer and closer

together. 3D and virtual environments (VEs) meanwhile are around for many years. The simulation industry is also very familiar with modelling, displaying and updating virtual environments in real time. Training simulators for tanks, ships, aircraft and military vehicles use VR and VE as a substitute for a real working environment. But in future the modes of interaction will increase, meaning that the VR and VE systems of tomorrow will allow us beside the interactions of today to sense, to feel, to hear, to smell, etc.

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