VIRTUAL PROTOTYPING OF TECHNICAL PRODUCTS USING A NEW AUDIOVISUAL VR SYSTEM

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Abstract. *Virtual Prototyping is an important tool to verify and optimise product features in the early design phases. Using digital product models many simulations of the system behaviour can be carried out and therefore costs and time can be reduced. For the development of innovative complex technical systems the applied models should comprehend the most important product properties. Today there are still deficits in modelling and evaluating the acoustic behaviour of technical products what is important for consumer goods and automobile industries.*
A flexible audiovisual projection system is configured which combines the stereoscopic projection with the acoustic reproduction method: Wave-Field-Synthesis. This new technology enables a realistic sound impression generated by a closed circle of loudspeakers around the listener area. For this the scene description is needed which provides the sound reproduction synchronously with the visual animation of machines, cars and other technical products. Empiric measured sound signals of function components (engine, gear-wheel, belt gear, bearing, guidance) are represented in the model by sound nodes and provided by a database.
The paper describes the goals of a new audio visual VR system, the use of virtual prototyping in early design phases as well as the method of Wave-Field-Synthesis as an innovative sound reproduction system for a realistic representation of acoustical behaviors of technical products in mechanical engineering.

Keywords*: Virtual Reality, Virtual Prototyping, Acoustics, Wave-Field-Synthesis, Design optimization*

1. INTRODUCTION

Today product development dominates manufacturing time and costs, which could be contradictory to high standards of quality. The use of computer based tools enables the representation of product properties and their optimization before first physical prototypes have to be build. One of the goals for the representation of product properties is the use of the *Virtual Reality* technology - a multimodal human-computer-interface with stereoscopic projection for spatial visualisation of 3D-object. Therewith an immersion in the virtual scene becomes possible. Furthermore this enables an easy comprehension and understanding of complex contexts and relations, which are mostly only clear for experts. Using intuitive interaction tools the user can navigate in the VR scene, manipulate and investigate the scene content.

Present systems in the VR are often limited by only using stereoscopic projection as visual interface of information. Even a large amount of visual perception is covered very well; only information of visible objects can be transferred. Therefore the transferable amount of perception information is limited. The spectrum of the perception should be extended, because nowadays more realistic immersion and presence are expected in VR environments. This is why acoustical and haptic perceptions become more importance in current VR systems.

Product development takes the acoustic behaviour of technical systems into account. Thus the allowed noise level of a machine is already legally prescribed from ergonomic point of view. Beside the noise level an efficient analysis of the frequency response must be considered for acoustic product evaluation.

In the area of the consumer goods industry the so-called *sound design* is used to optimize the acoustic behaviour of products. This is done mostly empirically and dependable statements are only possible after the manufacturing of first prototypes. Therefore the goal in VR systems is to include acoustics analysis and synthesis in the early phases of engineering design by means of virtual prototyping.

2. VIRTUAL PROTOTYPING IN EARLY DESIGN STAGES

Figure 1 shows the well known design process and the application of software tools for the virtual prototyping. Due to the coordinate application of the suitable software tools in each design phase virtual prototyping can be successful applied for the development of new machines and high technology products (Höhne et al., 2005). VR is one of the key technologies that integrates the possibilities of virtual prototyping.

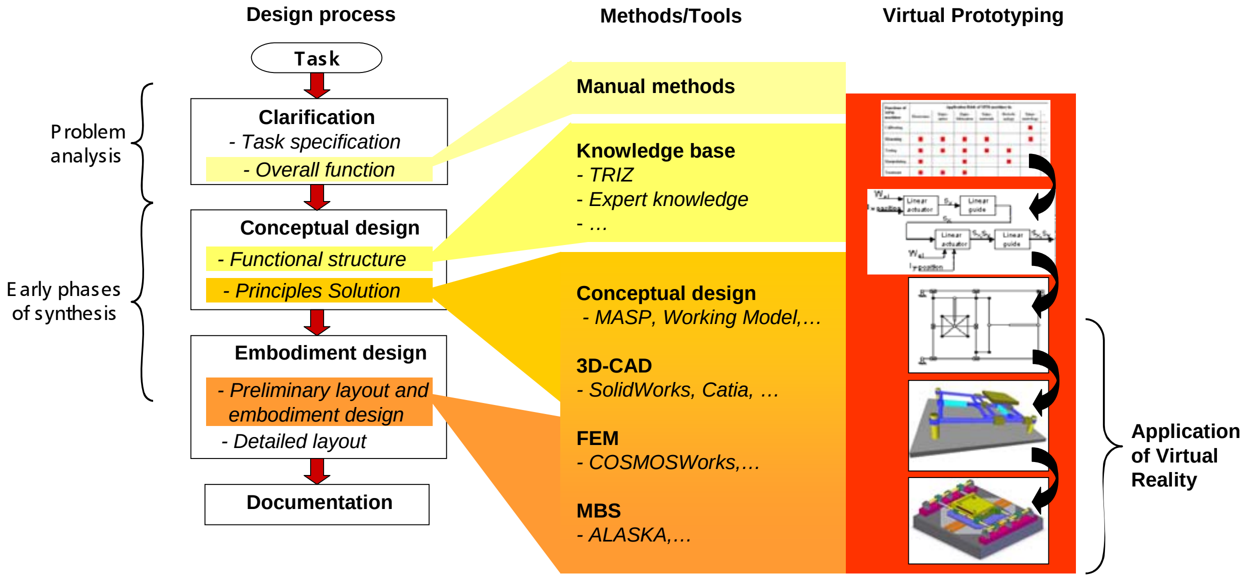

Figure 1. The main steps of the design process and tools for virtual prototyping

In general the virtual prototyping starts during the conceptual design. Based on the favorised functional structure possible solution principles can be computer-based developed by using e.g. configuration matrix, effect catalogues or known conceptual design solutions. The function elements of the solution principles are often described with simplified geometric representations or symbolic elements. Series of calculations of the behaviors are possible on this level of abstraction (e.g. working space analysis, error and tolerance analysis, kinematic and static analysis). The predominant question is the analysis, simulation and optimization of motion concepts to find preliminary layouts. The use of special software tools (like Matlab, SAM, WorkingModel, Watt) supports this process. The using of VR in this early design stage can merge the results of different calculations to find a good solution principle to support the determination of basic embodiment design parameters, which are necessary for the model transfer into a CAD system, for finite elements analysis as well as multi-body simulation. In the phase of embodiment design the using of VR is state of the art in order to clarify e.g. working space or collision problems.

Virtual product development focuses currently on the presentation of product properties over the visual human information channel. But the reachable optimization in VR depends on impressions, observations and reactions of the involved persons. Therefore the aim is to include further sense organs. In product development this is primarily the acoustic and haptic sense.

3. AUDIOVISUAL VR SYSTEM FOR VIRTUAL PROTOTYPING

3.1. The audiovisual VR system called FASP

In 2006 an innovative VR system was build in the Virtual Reality Competence Centre at the Technical University of Ilmenau in Germany (Fig. 2). This VR system (Flexible Audiovisual Stereoscopic Projection system - FASP) combines stereoscopic projection and sound reproduction by means of the Wave-Field-Synthesis method. The stereoscopic projection setup has three flexible projection walls, while two are movable. Immersion grade, degree of freedom as well as size of the FASP installation can be adapted depending on the application and number of persons inside the VR system. Figure 3 shows the three possible installation setups of FASP. The condition for the reproduction of the sound field using the Wave-Field-Synthesis method is to have a closed circle of loudspeakers around the listener area. The FASP installation has 208 loudspeakers.

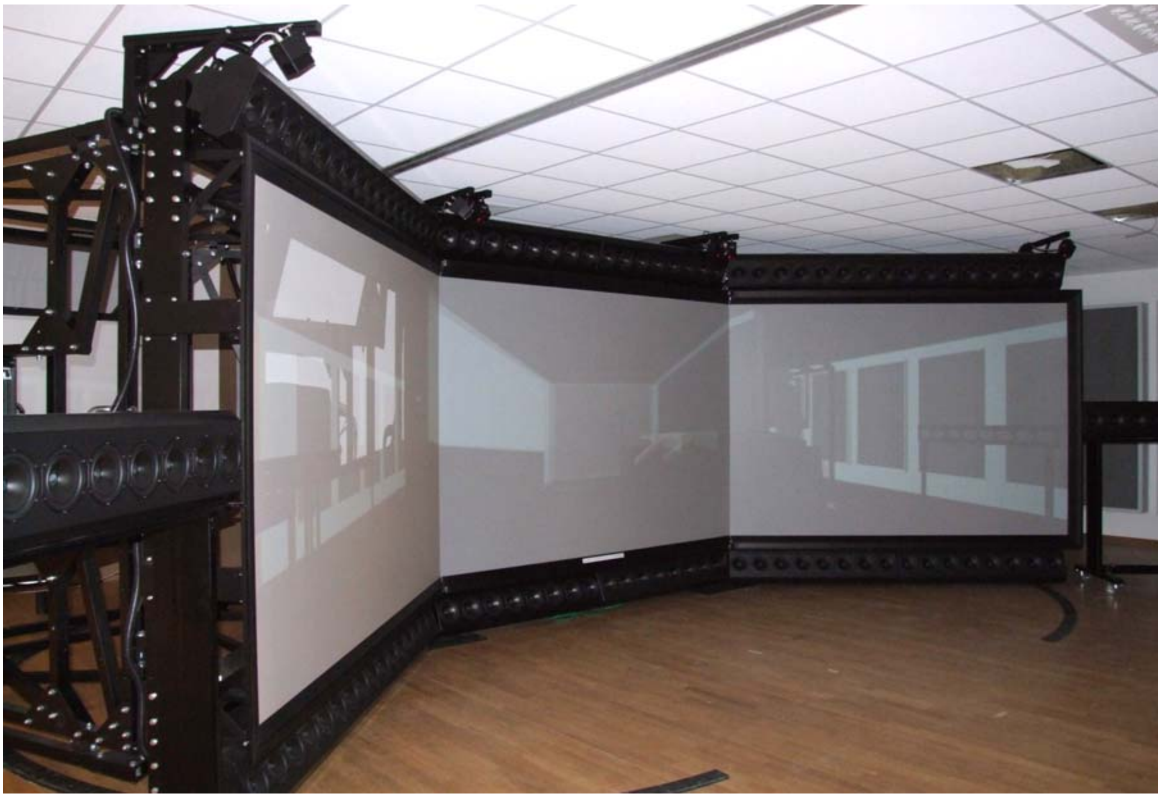

Figure 2. Audiovisual VR System at the Virtual Reality Competence Centre in Ilmenau

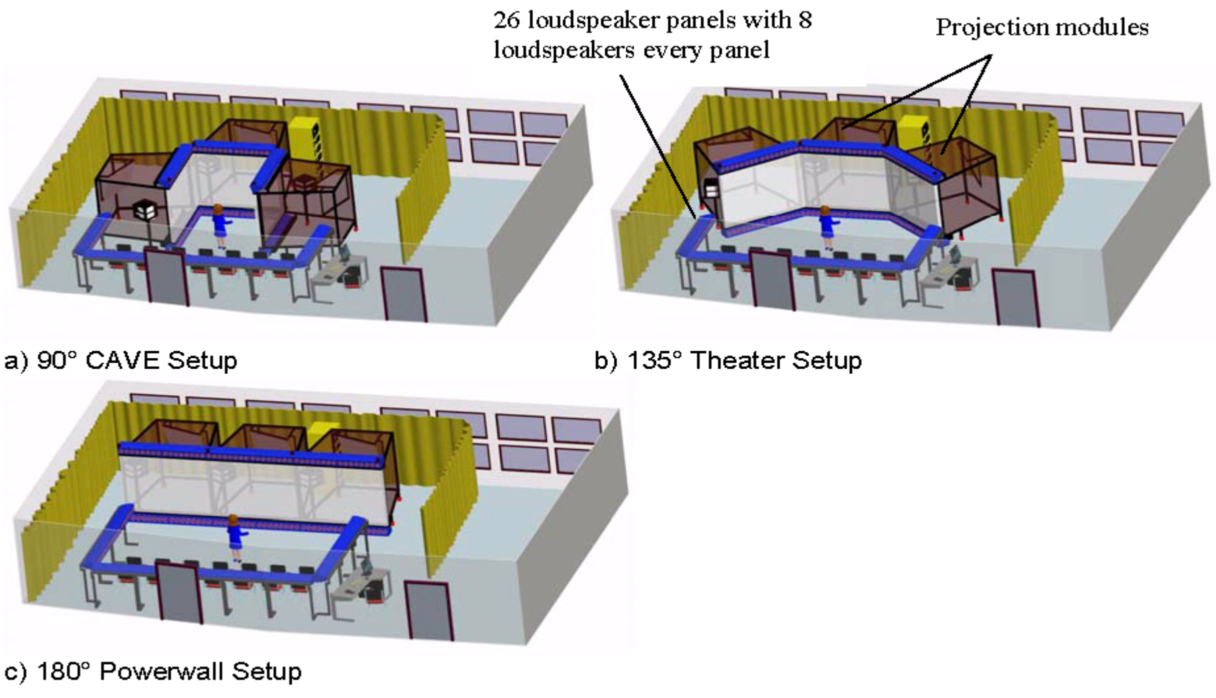

Figure 3. Possible setups of the audiovisual VR system in Ilmenau

3.2. Acoustic Reproduction by Wave-Field Synthesis

Over time different methods for the reproduction of spatial sound have been developed. In general they can be grouped into discrete multi-channel loudspeaker setups, binaural reproduction and multi-object audio reproduction. The advantages and disadvantages of those methods are described in (Brandenburg, Brix and Sporer, 2006).

The multichannel loudspeaker reproduction is based on discrete multichannel loudspeaker setups, like the well-known standard 5.1 surround format, which uses three front, two rear speakers and the low frequency effect channel. Its main drawbacks are the restriction for the listener to stay at an optimum fixed seat. This means, a good spatial impression and immersion is restricted to a very small region of the listening area, the so called 'sweet spot'. In addition the optimum performance can only be achieved if there is sufficient room for 5 to 6 loudspeakers to be placed at a predefined position and if the reproduction room meets some acoustical requirements. The problem that the sweet spot is limited to a small fraction of the reproduction room limits the sound quality, when a number of people is supposed to listen simultaneously. Therefore a plausible, natural-sounding 3D-display is not feasible with this technique. Most efforts to improve multi-channel audio by introducing a larger number of loudspeakers are still limited to a fixed configuration of loudspeakers and limited in their performance.

A technique called Wave-Field-Synthesis (WFS), pioneered by Delft Technical University and developed by Fraunhofer IDMT for many market applications, can overcome the limitations of todays multi-channel (loudspeaker) reproduction and binaural (headphone) reproduction (Berkout and De Vries, 1993). WFS permits the reproduction of a sound field, which fill nearly the whole reproduction room with correct localization and spatial impression (Boone, 1995; De Vries, 1996; Verheijen, 1998). The result is the possibility to move while listening in a similar way as to watch a hologram while changing the position. WFS is based on the wave theory concept of Huygens: All points on a wave front serve as individual point sources of spherical secondary wave fronts. This principle is applied in acoustics by using a large number of small and closely spaced loudspeakers (loudspeaker arrays) (Fig. 4). Each loudspeaker in the array is fed with corresponding driving signal calculated by means of algorithms based on the Kirchhoff-Helmholtz integrals and Rayleighs representation theorems.

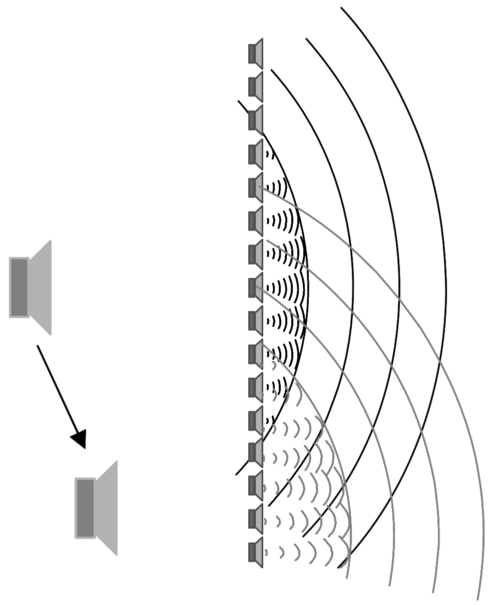

Figure 4: Wave-Field-Synthesis based on the wave theory (Brandenburg, Brix and Sporer, 2006)

For WFS these 3D-integrals are approximated for a finite number of identical loudspeakers placed in one plane. Without additional influence of the reproduction room the superposition of the sound fields generated by each loudspeaker composes the wave field in this plane perfectly up to the aliasing frequency. The aliasing frequency is given by the distance between loudspeakers. WFS enables an accurate representation of the original wave field with its natural temporal and spatial properties in the entire listening space only limited by the near-field properties of the loudspeakers used.

Virtual sound sources (point sources) can be placed anywhere in the room, both behind the loudspeaker arrays as well as inside the room (focus sources). The acoustical properties of the reproduced sound scene can either be the properties of the recording room, the properties of a prerecorded different venue or obtained from artificial room models. These properties can also be reproduced using plane waves (Fig. 5).

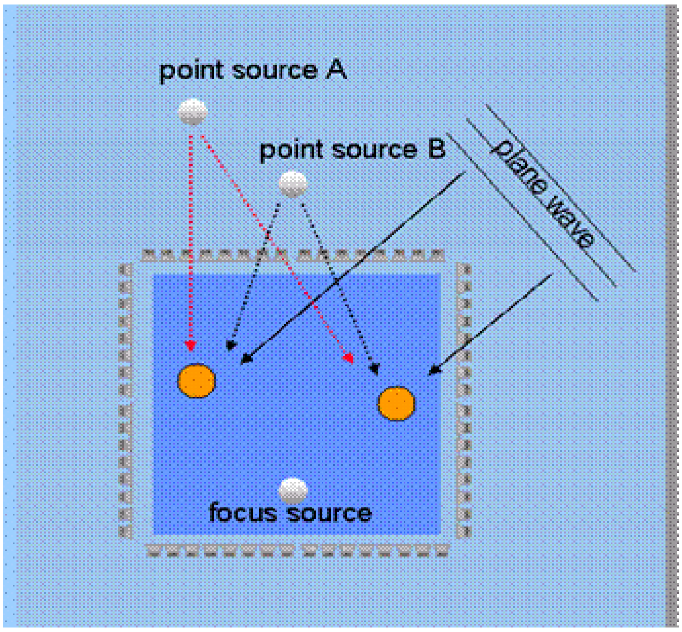

Figure 5: Reproduction of sound sources and plane waves (Brandenburg, Brix and Sporer, 2006)

This new technology enables a realistic sound impression independent from the listener position and therefore is a strong tool for machine acoustics analysis and sound design. If the user is rotating or moving the VR scene sound source movements can be heard in real-time, because the WFS algorithms render the acoustical scene in real-time.

Currently studies investigate how WFS can be used as reproduction method for machine acoustics modeling, simulation as well as sound design.

3.3. Virtual audiovisual product models

Acoustical models can be deduced from three basic steps of sound creation (Fig. 6). The important step for reproduction by means of WFS is the sound radiation. First concepts and ideas are based in the discretization of e.g. a machine surface in several points for the sound radiation. At these points WFS sound nodes could be placed. Each sound node could be represented as a point source with omni directional characteristics. Currently WFS software supports the simultaneously reproduction of up to 32 independent omni directional sound sources. In this way up to 32 positions have to be found on the surfaces of a technical system, which describe a sound radiation of the machine to the listener.

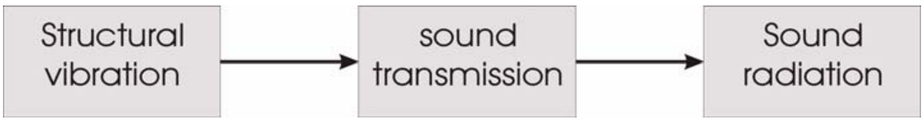

Figure 6. Steps for sound creation

Nonetheless the coupling between acoustical models, simulations and WFS for a better understanding of the acoustical behavior of suitable virtual product models in the product development should be further and intensively developed.

First developed virtual product models were provided on the basis of available tool machines and utility vehicles. 3D-CAD models are the basis for generating the geometrical VR representations and the functional modeling of systems (Fig. 7). To represent acoustic information in the virtual product model the available scene graph was extended. Classical scene graphs enable the acoustic information on the basis of VRML-nodes. The scene graph contains acoustic parameters like volume, position and radiation direction. For WFS several other parameters like distance dependent loudness or sound emission angle for plane waves are necessary.

The description of the acoustic scene by means of single sound sources enables the interactive manipulation of parameters, which leads on a real-time basis to the adaptation of the sound field. Audio nodes are placed spatially at the machine components or in the connection points between two components as well as on the surface of complicated devices and machines. In the scene graph the audio nodes are related to the geometry nodes or common assembly nodes, so that these will be moved respectively to the movement of the geometry in the scene.

For the representation of the acoustic behavior there is currently no acoustical synthesis from virtual product models as already described above. Current projects in the FASP are still working empirically i.e. measuring “dry” sound sources, which were captured individually (separate sound sources of single components or sub-assemblies). Dry sound sources mean that the sound information is only referred to the sound source without additional background noise or room information.

Real components have a sound radiation, which is not describable by the use of simple audio nodes. Hence, in the current first applications the VR scene is divided into areas in which the sound field is nearly steady and therefore no direction dependent radiation exists. These areas are called portals. Figure 8 shows the main portals of a revolving automatic assembly machine. With the entrance of a main user by head tracking the application loads the suitable sound sources, so that the sound field is adapted. Now in every portal the sound field is generated.

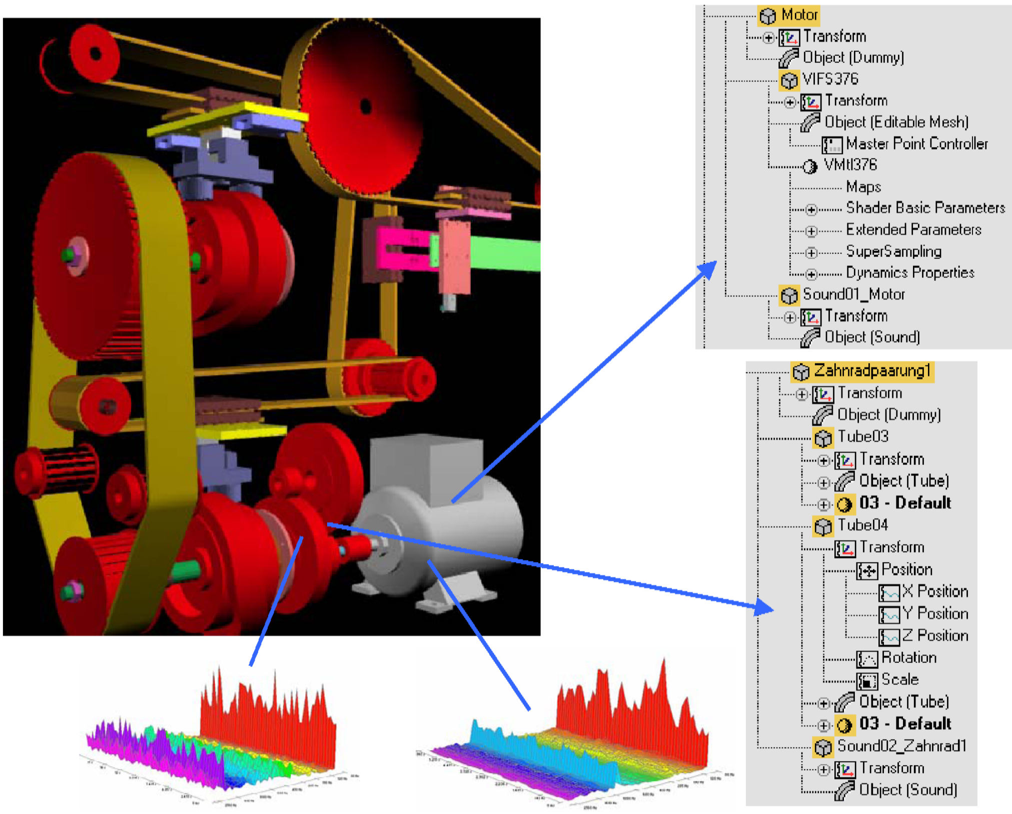

Figure 7. Audio visual VR model of a pick&place unit using scene graph for acoustic information (in Husung, Höhne, Lotter, 2007)

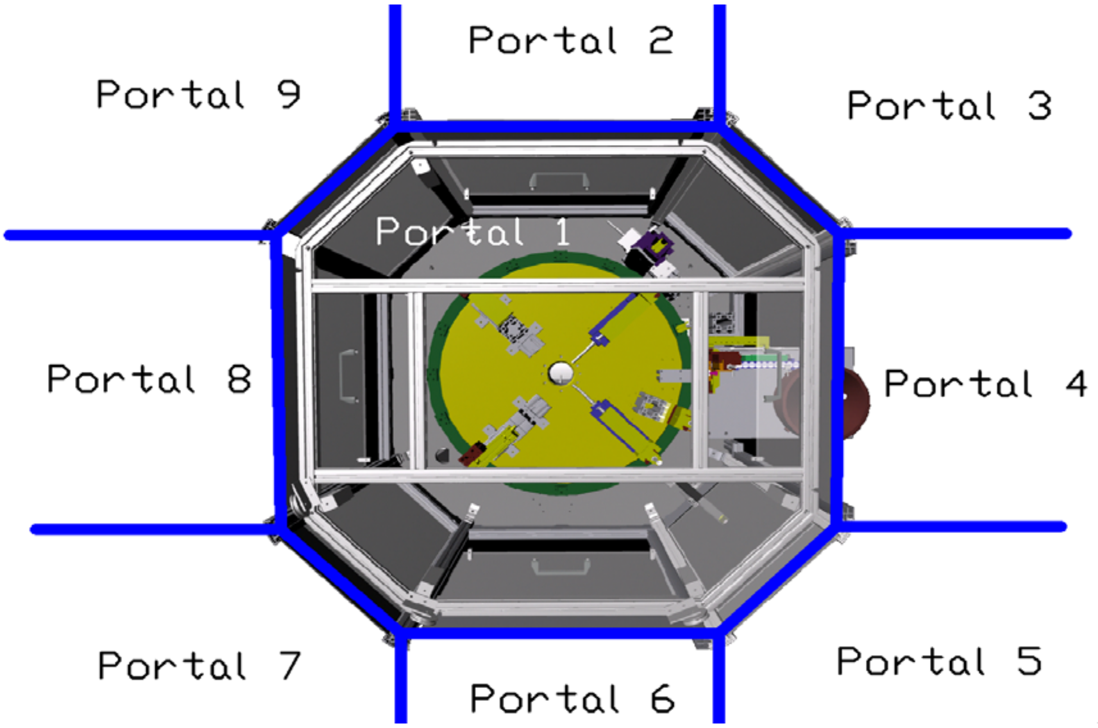

Figure 8. Portals in the model of a revolving automatic assembly machine

4. CONCLUSIONS

Virtual Prototyping connected with the use of extended Virtual Reality opens new doors for the evaluation of technical systems in the product development. Stereoscopic projection and real-time interaction with the virtual scene complemented with acoustic reproduction are powerful tools in the early phases of engineering design.

Following features and new possibilities are available using the FASP system:

- real-time interaction and visualization of scenes including sound reproduction
- design reviews with efficient recognition of geometrical and acoustical product properties and failures
- efficient interdisciplinary work by easy understanding of complicated contexts
- efficient education and training using realistic virtual prototype

Further research deals with the integration of machine acoustics analysis, synthesis and design in virtual prototyping for future virtual reality systems. Ongoing investigations in the FASP system aim to determine this integration and the road map for developing extended product models with acoustical properties.

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