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EXTENDED PRODUCT MODEL FOR SIMULATION BASED DESIGN

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ABSTRACT

The development of innovative complex technical systems with the intention to reduce costs and time is hardly feasible with conventional resources. Therefore Virtual Prototyping has asserted as an important tool for the verification of system features in the design process. Based on digital product models, various simulations of the system behaviour can be carried out. Those are to say the functional and acoustical properties of designed products. The verification of these desired properties requires special simulation models.
The aim is the extension of the possibilities for product optimisation in the early stages of design including the acoustic product behaviour by use of Virtual Prototyping. The subject of research is the application of the wave field synthesis for machine acoustics in immersive environments and the methodical generation of necessary product models. The acoustic properties can be valued by means of a new audio-visual VR-system under psychoacoustic consideration.

Keywords: Virtual Reality, Virtual Prototyping, Acoustic, Wave-field-synthesis, Optimization in Design

1 INTRODUCTION

The development of technical systems requires decisions on the important properties in the early stages of the design process. This is complicated by a large number of uncertain factors and influences on the properties and their often complex interconnections. Therefore tools are needed which encourage an interdisciplinary discussion and support a decision about the product features by different simulation and realistic presentations of the results. The type of tools is called Virtual Prototyping providing complex product and process simulations based on parametric digital product models [3]. The results can be evaluated interdisciplinary in multimodal immersive presentations using the technology Virtual Reality (VR) [1].
VR is a synonym for intuitive interaction with 3D-objects in a virtual world which implicates advantages in product development. The user can immerse and move in the VR-scene as well as interact with designed products represented as virtual prototypes. So VR enables a better recognisability of problems, better appraisal and feedback from confrontation of design solutions with realistic vicinity. VR supports also the collaboration with specialists from other areas. Thus can be increased the quality of design results.

2 VIRTUAL PROTOTYPING IN SUPPORT OF PRODUCT BEHAVIOUR

The development of technical systems consisting of heterogenic function units or skimpiest micromechanical components requires the handling of complex structures [9]. Precision Engineering determines such new demands [6]. The regard of tight dimension and form tolerances requires adequate simulation methods, like coupled MBS-FEM simulation. These innovative methods are used for example to test behaviour and design of new concepts of high-precision mechanisms and handling units. An important aid is also spatial visualisation in real-time.

New concepts of a handling unit are characterized by high clock speed which needs special dynamic mechanism to succeed this. For this several gear concept variants were build and analyzed with tools of virtual prototyping. The system MASP (Modeling and Analysis of Solution Principles) [2] enables the designer in the early design stages to carry out design guidelines such as minimum error configuration, function separation or integration, direct and short power transmission, symmetry and well constraint design. After the decision on one solution principle, several virtual prototypes of the pick and place unit were designed and analyzed (Fig. 1).

Figure 1. Concept of the handling unit

Virtual product development currently focuses 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 involved persons. Furthermore the demands on product development and the limits of the visual perception require the inclusion of other senses. In product development, these are particularly the tactile and the auditory sense. The consideration of the auditory sense and the use of immersive acoustic systems allow the acoustical optimization of technical systems in early design stages and the execution of sound design. An important application area is the consumer and automobile industry with strong ergonomic conditions.

3 CONCEPT OF AN AUDIOVISUAL VR-SYSTEM

In 2006 a system for creating a realistic acoustic sound impression was build at Competence Centre “Virtual Reality” at TU Ilmenau (Fig. 2). This is a flexible 3-side-projection system with the combination of stereoscopic projection and acoustic wave-field-synthesis.

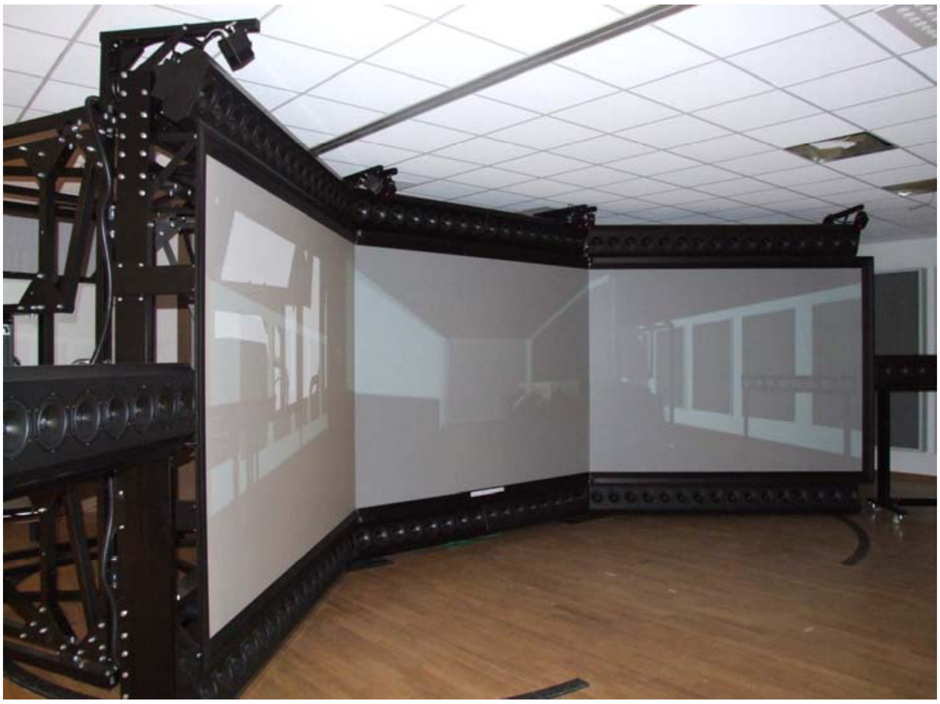

Figure 2. Audio-visual VR-system at Competence Centre Virtual Reality

To reproduce spatially sound events, different principles are possible. The most common method, the loudspeaker stereophony, generates the sound representation between a few loudspeakers. Different loudspeaker setups are possible from which the most current are the 2/0 stereophony as well as the 3/2 stereophony. Indeed there are clear restrictions: sound events between listener and loudspeaker are not reproducible. Furthermore the strongly restricted hearing zone (the so-called "sweetspot") limits the application because only few people come to the impression of spatial sound. The binaural acoustic allows for a user a realistic hearing impression by calculation of the HTRF (Head Related Transfer Function) from the tracking data. The HTRF takes into consideration the head and outside ear form originating sound pressure and time differences of the sound. For this technology often headphones are used which limit the movement area. Hence, another concept overcomes these limits by generation of the surrounding sound field. This method is called wave-field-synthesis.

Wave-field-synthesis is an acoustical reproduction concept for realistic sound fields in any virtual environment based on Huygens Principle. A primary sound source which emits spherical wave fronts can be represented by addition of endless secondary sound sources. These sources are replaced by loudspeakers. The condition for the reproduction of the sound field is a closed circle of a high number of loudspeakers around the listener area (Fig. 3). At the system in Ilmenau there are 208 loudspeakers. Based on the Kirchhoff-Helmholtz integral of wave theory the sound field can be calculated [7]. The loudspeakers have a defined distance calculated by the signal theory. The distance determines the Aliasing Frequency which is the highest exact renderable frequency. Currently the distance is 17cm what means the Aliasing Frequency is about 1000Hz. Virtual sound sources can be placed as point sources behind the loudspeakers or as focused sources in front of them. Room acoustic properties can be reproduced with plane waves [7].

This new technology enables a realistic sound impression independent from listener position. This controllable and spatial playback of sound sources (gears, engines, bearings etc.) is a capable tool for machine acoustics analysis and sound design. The user can manipulate the VR-scene interactively because the wave-field-synthesis algorithm is rendered in real-time. Currently studies investigate how wave-field-synthesis can be used for machine acoustics simulation and sound design.

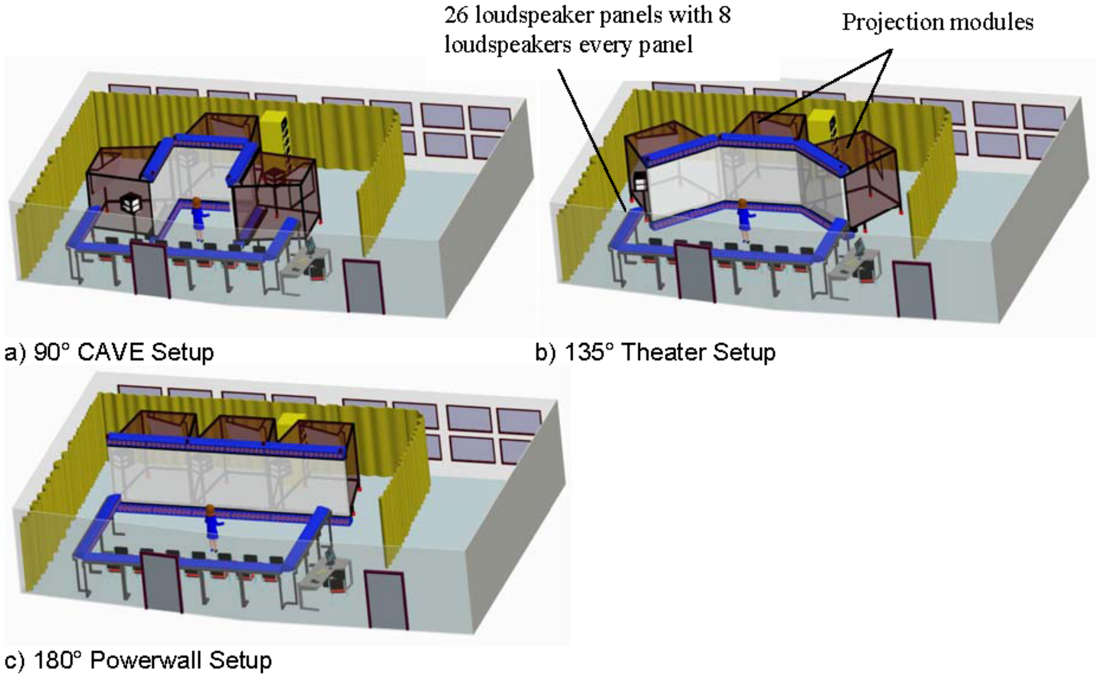

Figure 3. Model of the flexible audio-visual VR-system

The use of wave-field synthesis for psycho acoustical investigations during product development requires audio-visual models which describe the acoustical behaviour depending on gestalt and functional input parameters of technical systems. The purpose is to develop an extended model which is precise enough concerning the psychoacoustic assessment. One important research topic is to determinate of the requirements on the VR-system and these audiovisual models. To the requirements belong:

- necessary spatial and temporal synchronisation limits between visual and acoustical events
- necessary number and position of the sound sources for a realistic sound impression.

A difficulty at the combination of stereoscopic projection and wave-field-synthesis is the observance of spatial localization limits between the visual and acoustical events. The stereoscopic picture is nearly optimum only for one tracked person. There are some spatial distortions based on the projection and viewing conditions. All other users see a distorted image. Furthermore they see the 3D-model at another position. The reproduction of the virtual sound sources by the wave-field synthesis is exact for a group of users. They can hear the sound sources at the same position. So accrue two different localization points for the visual and acoustic incidents. This effect becomes troublesome above a horizontal threshold angle of 6° to 8° between user and the both incidents (Fig. 4) [5]. The threshold originates from the acoustic direction perception. Using the Powerwall configuration (Fig. 3) this threshold is reached quickly. Fig. 5 shows the possible position of an audiovisual object in front of the Powerwall which does not become troublesome depending on the users position. The task of the ongoing research is to ascertain the influence during design reviews and to optimize the interconnection of stereo projection and wave-field synthesis to reduce the limits. In the median plane the threshold for the direction perception has a much larger amount, up to 17° and more. So in the median plane the spatial localization limits are nearly indifferent for the combination of stereoscopic projection and wave-field-synthesis.

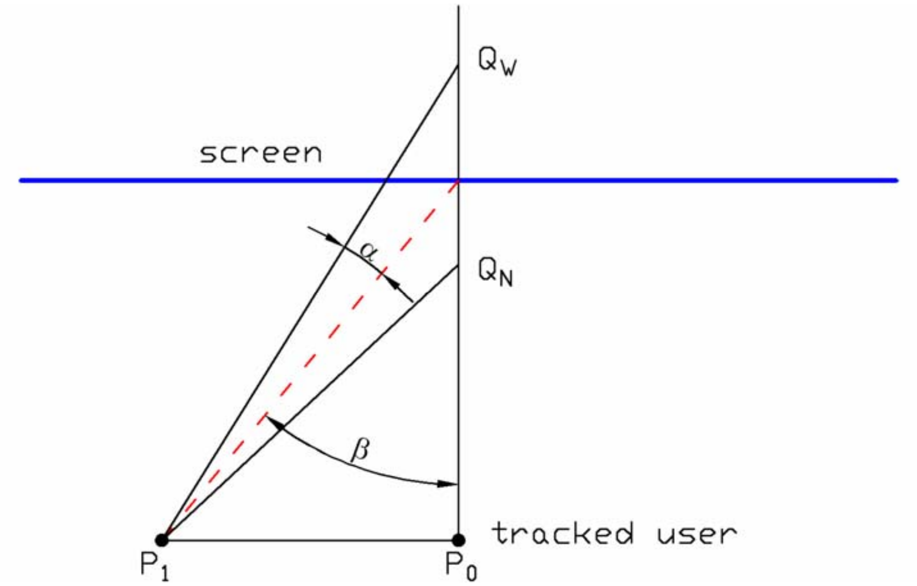

Figure 4. Divergence of the sound event and the stereoscopic picture as a function of consideration angle of a not tracked recipient. Here are, B the projection screen, β the divergence angle of the recipient P1 of the position P_0 orthogonal to the screen, α the acceptable divergence angle between picture and sound, Q_W and Q_N are the limits between which audiovisual objects can be placed

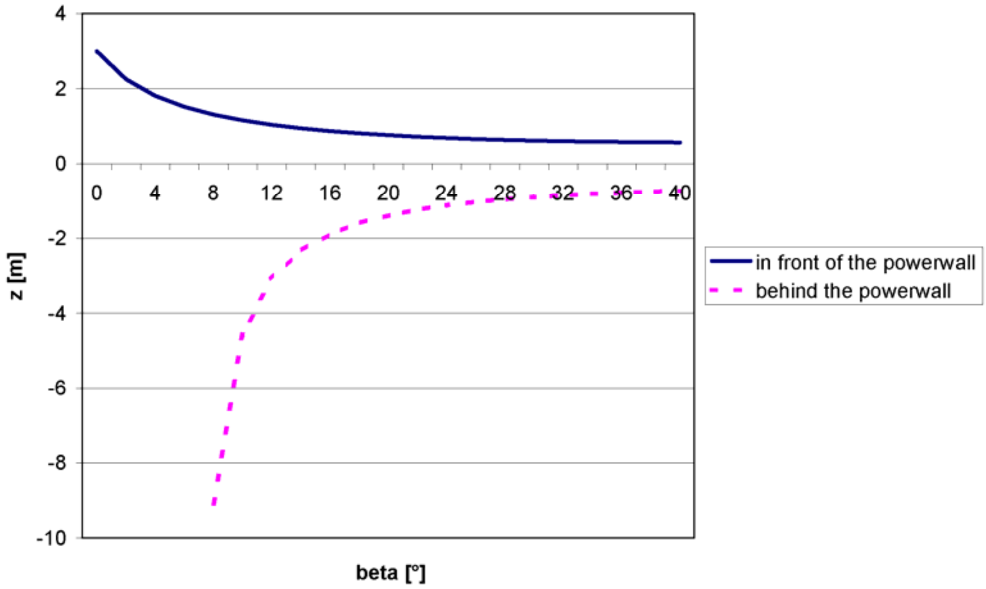

Figure 5. Positions of audiovisual models on Powerwall depending on user

Another difficulty is the temporal synchronisation of picture and sound. For a realistic sound impression the latency between picture and sound event should not exceed a certain threshold. This permissible threshold depends on many factors. The latency is determined by the rendered data. So the picture or the sound event can start later. Results of previous investigations in literature show that in immersive audio-visual environments a maximum latency time of 85 ms [4] or 70 ms [8] should not be exceeded. The difference in the amount of the allowed latency times depend on the used scenarios. An acoustic signal which lags the visual signal is rather accepted than a visual signal which lags the acoustic signal.

Own researches show that the allowed threshold for the scenarios in the VR-system depends on the type of sound events. For uniform continuous sound events the threshold is nearly indifferent. However it is crucial for impulse and recurring events. Ongoing research deals with specification of those events.

Figure 6. Sound Formation

The acoustical model for wave-field synthesis can be deduced from the three steps of sound formation (Fig. 6). The most important step for wave-field synthesis is the sound radiation. By discretisation of the machine surface in several points the radiation can be reproduced. At these points wave-field synthesis sound nodes are placed. Each sound node represents a point source with a sphere characteristic. Currently wave-field synthesis software supports up to 32 independent sound sources with sphere characteristic. So on the surfaces of a technical system up to 32 positions have to be found, which describe the sound radiation around the listeners. The sound sources on the machine surface itself are superposition of all sound transmission paths from the structural vibration in discrete points.

The sound sources are represented as special sound nodes in the scene graph. These nodes contain parameters like position, intensity, direction and the link for the audio file. These parameters are well known from VRML sound nodes. Furthermore these sound nodes contain information about plane wave characteristic, distance dependant flags and wave-field synthesis options, which are not comprised in standard VRML. For creating a scene graph some VRML sound parameters has to be interpreted new.

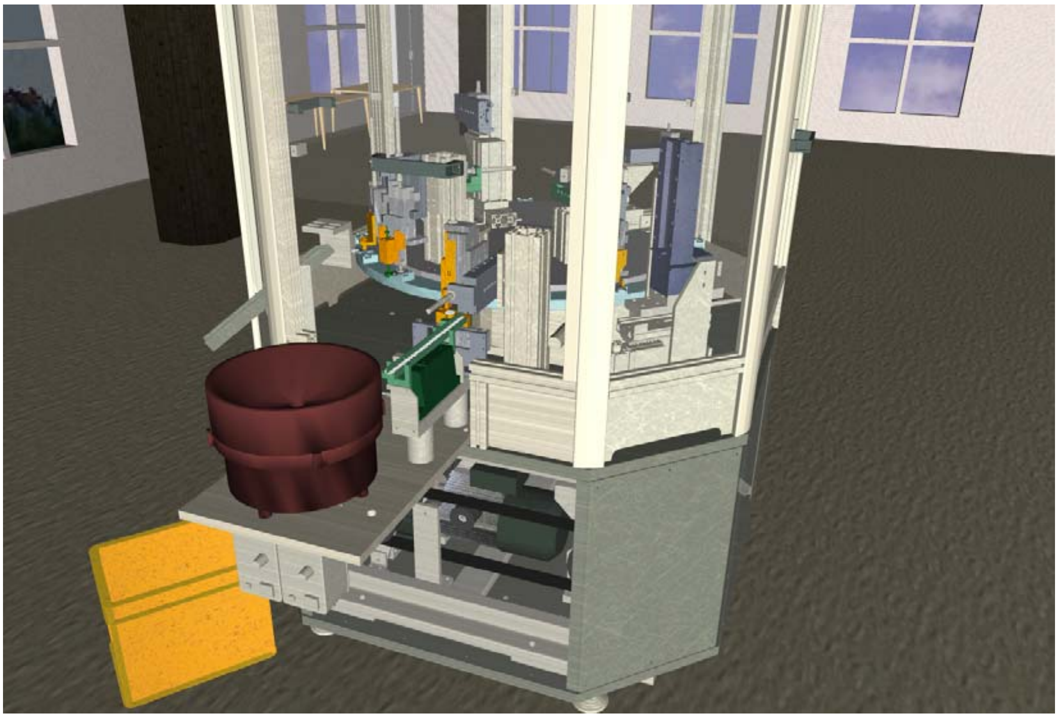

Figure 7. VR scene of a revolving automatic assembly machine

Wave-field synthesis is not able to describe and model reflection, refraction, diffraction of acoustic waves. Hence, it must be always checked that no objects exist between the sound source and the recipient. This can be done, for example, by using a ray which checks for objects between the active sound source and the listener. But this method needs many calculation resources and delays the VR scene. Therefore currently another method is indicated. The VR scene is divided into portals which represent a region in that the surrounding sound sources are equal in frequency response and standard volume. For a revolving automatic assembly machine model (Fig. 7) the portals are shown in Fig. 8. Inside each portal the sound radiation of the machine surfaces is nearly similar. The most important portal is the portal 1, in the inner machine with an entirely different sound radiation than in the other portals. For each portal appropriate sound nodes are active to reproduce another sound field in the VR scene. The respective portal sound is activated in relation with the user position indicated by head tracking. The questions for the ongoing research are whether the method with the portals is sufficient for a psychoacoustic assessment and how the transition must be arranged between the portals to excite a homogeneous sound field.

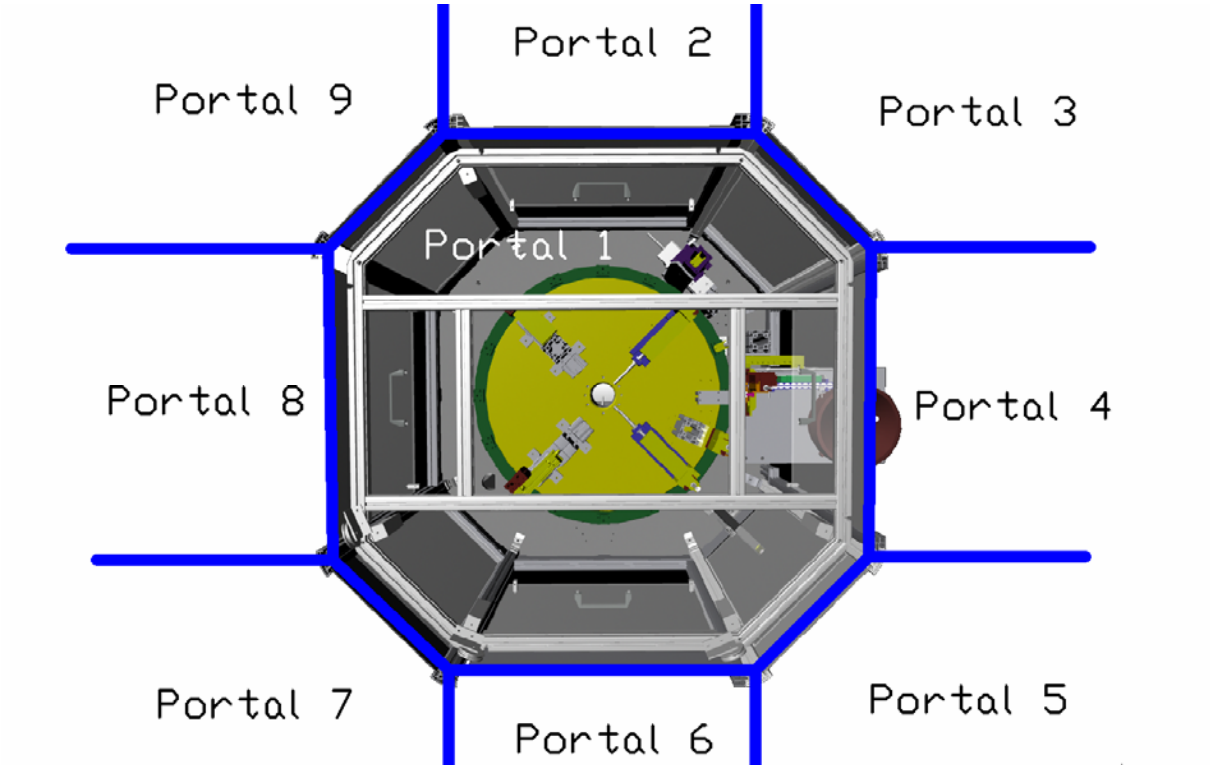

Figure 8. Portals in the model of a revolving automatic assembly machine

An important property of these models is the complexity of the data which determinates the calculation time. To get acceptable latency times the audio-visual models are divided into a shape representation, like conventional VR-models, and a sound representation for the acoustical behaviour.
Different methods can be used for the simulation of the acoustical transmission. The most accurate method is the numerical FE-Method. A more abstract but easier to calculate method is SEA (Statistical Energy Analysis). The decision about the optimal analyze method depends on required accuracy and the dominate frequency band.
Fig. 9 shows the structure of the audio-visual VR-system using FEM for simulation of acoustical transmission and BEM (Boundary Element Method) for sound radiation. Both methods need acoustical parameters of the structure. To reach realistic results the structure parameters are ascertained by experiments. As another consequence hybrid physical models are used. The parameters can be controlled for sound design by use of an users interface.
During real-time interaction the FEM und BEM calculation process is too extensive. So the simulation has to be done in pre-process and the results can be used during model interaction.

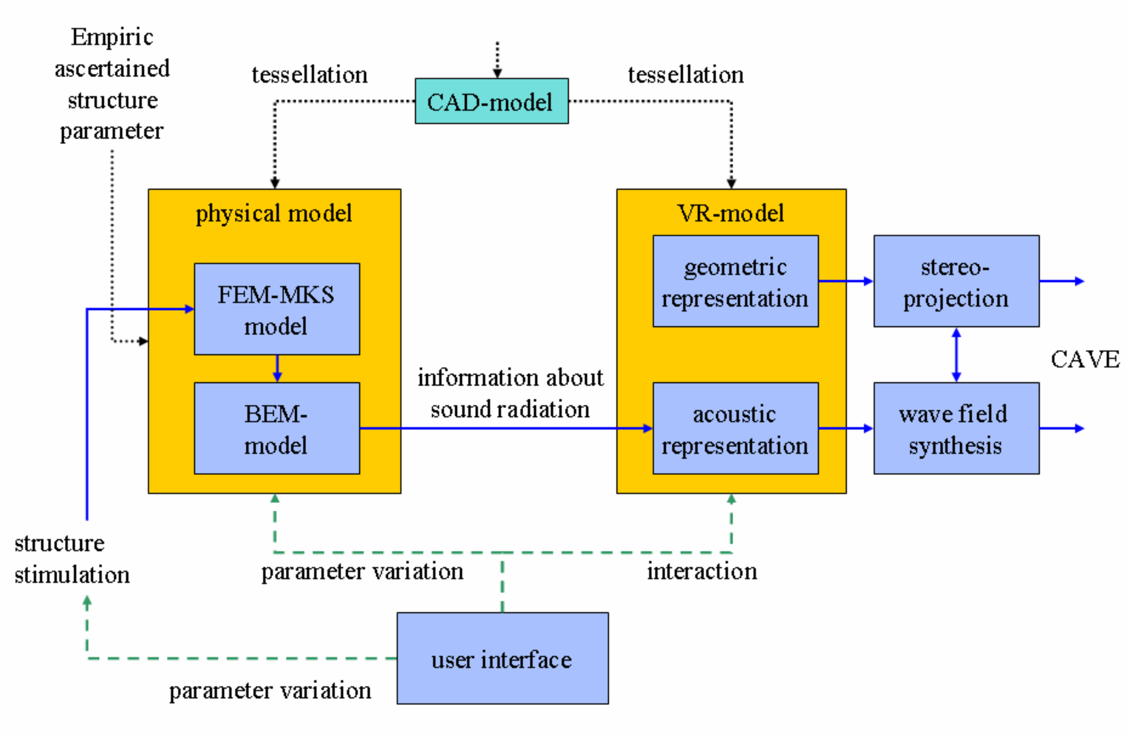

Figure 9. Data processing in the audiovisual VR-system

First models were created for assembly machines, like a pick & place unit (Fig. 10) and a revolving automatic assembly machine (Fig. 7). This investigations base on empiric measured sound data. Separate sound sources, called dry sources, of functional components were measured in the running machines using a condenser measuring microphone with almost linear frequency response. The challenge of this measurement was the isolation of the dry sources. So the machine components had to be decoupled and the background noise had to be insulated. Some machine components, like gears, could not be decoupled for the measurement. So the ascertain sound of the engine had to be subtracted from the measured gear noise using the frequency response.

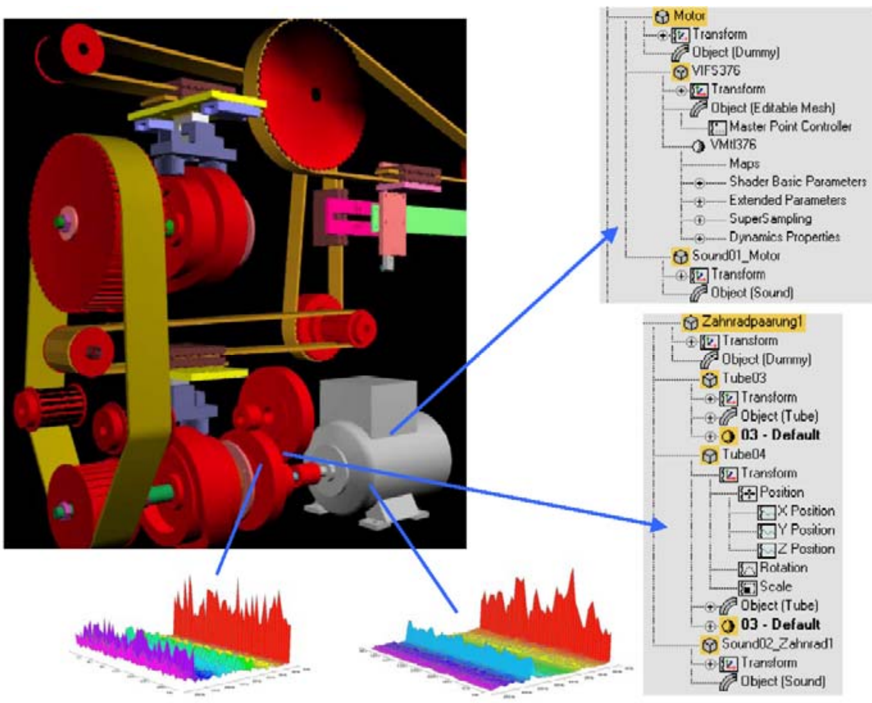

Figure 10. Representation of sound attributes in scene graph of a pick & place unit

The models were prepared in such a way that the sound events are synchronously in relation to the visual animation of the machines. Sound information of the components (engine, gear-wheel, belt gear, bearing, guidance) are stored in a database. Furthermore the parameter of the sound sources can be controlled during presentation. This enables to investigate sound interplays between different sound sources and different components. Therefore psychoacoustic investigations are already possible.

During a design review mostly the technical systems have to be placed close to the users in the VR scene. That way the sound sources are in front of the loudspeakers and have to be focused on the point of the virtual sound. In order to assure that all users have the same sound impression and hear the sound sources at same position the reconstruction area should be considered. It depends on the position of the active loudspeakers and the extreme position of the users. Fig. 11 shows the reconstruction area for a simple sound source in a rectangular loudspeaker area by creating a line which is orthogonal to the line between the sound source S and the centre of the loudspeakers R. This method can be transferred on the geometry of the VR-system. For the construction Thales circles are used which intersect the room centre M and corners of listeners position E (Fig. 12). This is done for each corner. For the audiovisual VR-system the result of the theoretical reconstruction area is shown in Fig. 13. The real reconstruction area is smaller by reason of psycho acoustic aspects. This area has to be considered during VR-presentation and in the VR-models.

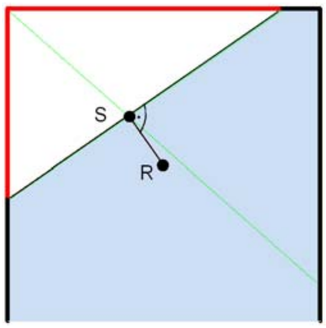

Figure 11. Reconstruction area for a single sound source in a rectangular loudspeaker area (red are the active loudspeakers, the blue area is the reconstruction area, S is the position of the virtual sound source and R is the centre of the loudspeaker area)

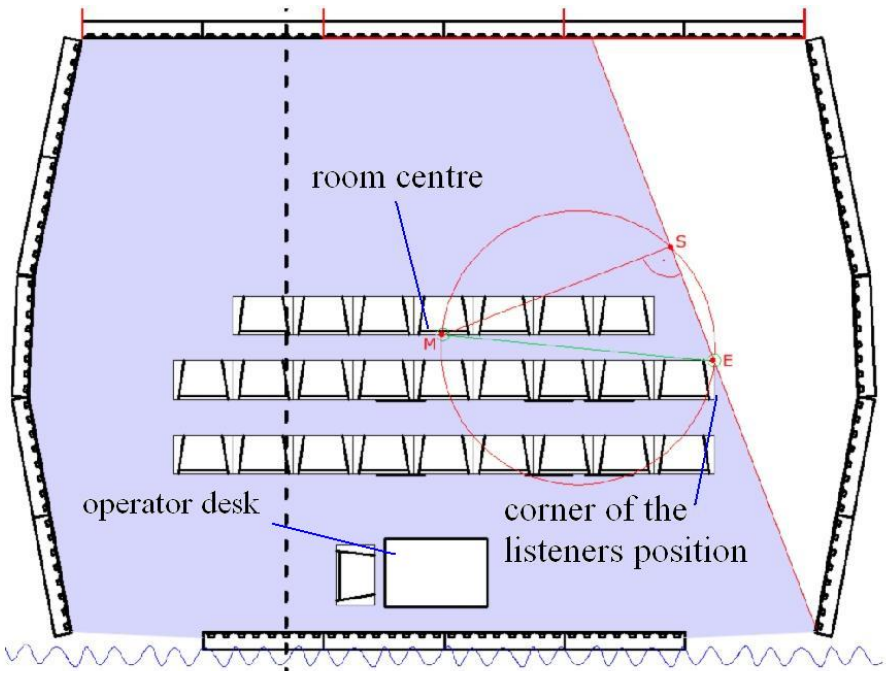

Figure 12. Calculation of the reconstruction area with Thales circles

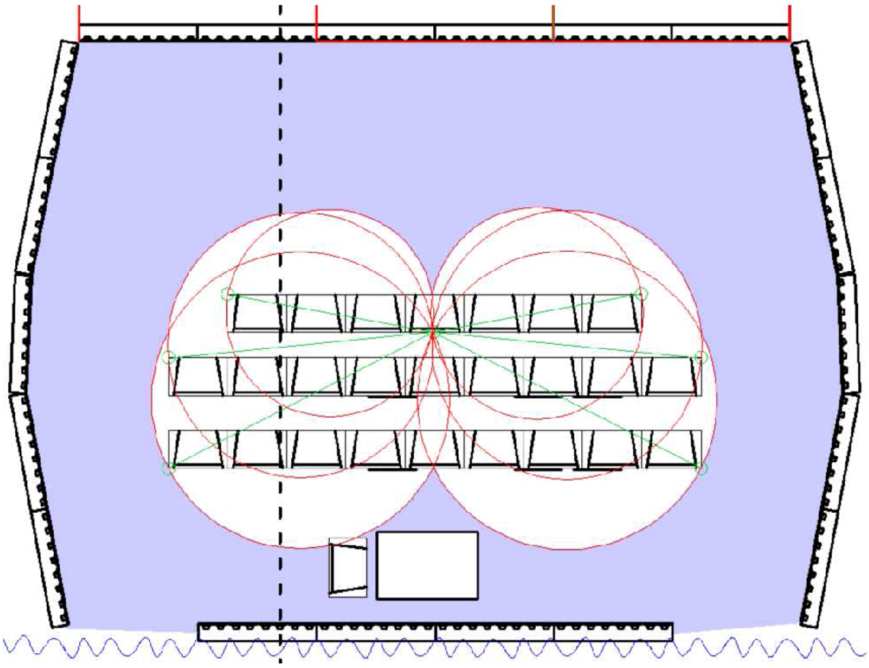

Figure 13. Final reconstruction area in the audiovisual VR-system

5 KEY CONCLUSIONS

Virtual Prototyping in connection with the use of extended Virtual Reality opens new potential for the evaluation of technical systems in the product development. Stereoscopic projection, interaction in real-time, complemented with acoustic perception in virtual space provide the user realistic impressions about the designed product. Therefore new possibilities originate for:

- interactive real-time visualisation of moved scenes with sound reproduction
- design reviews with efficient error recognition of geometrical and acoustical product properties
- efficient interdisciplinary work by easy understanding of complicated contexts
- retrenchment of physical prototypes
- efficient education and training using realistic virtual prototypes

Further research deals with integration of the audio-channel in Virtual Prototyping for machine acoustics and sound design in virtual environments like the presented VR-system. So the ongoing investigations have the aims to determine the potential of that integration and to develop extended product models for the consideration of the acoustical behaviour.

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