

Using Game Engines in Digital Manufacturing through Immersive and Collaborative Visualization Systems

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Abstract

This paper proposes a methodology for immersive multiprojection visualization of manufacturing processes. It admits sceneries with dynamic components and allows collaborative interaction among geographically distributed users. The proposal has several stages to convert the complex industrial project into a model suitable for visualization and interaction. The Quake III Arena engine is used as rendering core system, which is a free and open-source software. The method can be applied to CAD projects, models and simulations used in industry. The proposed ideas are then validated through the study of a real case associated with Shipbuilding and Offshore Industries.

Keywords:: Digital Manufacturing, Shipbuilding, Virtual Reality, CAVEs, Game Engines

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1 INTRODUCTION

Digital manufacturing is an initiative to define every aspect of the design-to-manufacture process digitally. An open data management platform is the ideal basis of Digital Manufacturing. This platform can support multiple disciplines, including product design, analysis, manufacturing, data sharing and communication, etc. It relies on advanced technologies such as CAD, CAE, real time 3D simulations, CAM, PDM, CAPP, etc.

Large and high-end engineering projects such as automotive, aerospace and shipbuilding are already engineered almost entirely digital. Their complexity demand assembly simulations using mockups to test the several stages of the process. As physical mockups have a very complex and high cost design, digital 3D mockups are good solutions. In practice however, this digital design is not as simple as it might first seem. In such a process a large number of concurrently working design teams are involved, resulting in the development of typically thousands of different parts, each modeled with the highest possible accuracy. For instance, in the case of the Boeing 777 airplane project, more than 230 geographically dispersed groups had to be coordinated and more than 350 millions of individual polygons from the graphical model of CAD datasets must be processed in order to obtain a 3D projection of the whole model.

Eminent problems in large-scale manufacturing arise from the potential overlaps of assembly parts and the difficulty in properly fitting all individual components together in a final product. In those contexts, Virtual Reality (VR) techniques can provide an interactive high-quality visualization solution for evaluation of the full CAD design and the whole manufacturing process [Dietrich et al. 2005].

Virtual Reality techniques make possible 3D visualization of industrial sceneries, offering a realistic and interactive interface for dif-

ferent production stages and processes, aiming to anticipate problems like overlaps of assembly parts, obstacles collisions, risky situations, etc. These techniques include several levels of interactivity and immersive technologies.

CAVE devices [Cruz-Neira et al. 1992], for instance, are room-size VR display systems. In these systems the generated images are distributed among computers and multiprojected onto several walls. Each individual projection contains a part of the total scenery, obtained from a process of simultaneous rendering. This way, each wall acts as a window to the virtual world. The use of such configuration makes possible, among others, to increase the immersion and interactivity degrees associated with the sceneries. Some semi-immersive desktop-based VR systems exist but an obvious limitation of them is that designers are susceptible to environmental disturbances, diminishing their true feeling of the scene. As a result, they cannot be fully immersed in the virtual environment to study and improve the product design efficiently [Choi and Cheung 2006].

If in the past decades the benefits of VR and its integration with digital manufacturing systems were focused in the static product design (visualization of the CAD project of the product), nowadays the state-of-art is to focus on the modeling and simulation of dynamical manufacturing plants as a whole process. The life-cycle of the product, the ergonomic of the workers, the localization and performance of the machines, the assembly steps have become to be simulated and visualized in immersive CAVEs.

Besides, such VR techniques and technologies, associated with recent efficient simulation and communication systems, have become a new paradigm for integrating different levels of production processes that are temporal and geographically distributed. The large engineering industries have physical parts produced by separated key players, each with their own sets of standards and terminology. So, one of the biggest obstacles in the widespread implementation of digital manufacturing is the weak interoperability and collaboration between various systems in product design, manufacturing engineering, and production floor documents. Breaking down the walls between these departments and maintaining the crucial digital continuity of the product life-cycle will greatly foster digital manufacturing, and therefore help manufacturers improve efficiency of processes and quality of products [Wald et al. 2005].

Thus, due to the distributed nature of recent high-end engineering projects, the possibility of virtual, interactive and collaborative immersive visualization of dynamic manufacturing plants have become an important issue which can determine a company/consortia success [Stephens et al. 2006] [Bigler et al. 2006]. The use of this new paradigm can reduce cost, complexity and time associated with the process. For instance, large industrial conglomerates such as automobile (Volkswagen, Ford and General Motors), aerospace (Airbus, Embraer) and the shipbuilding/offshore industries are integrating VR concepts in their manufacturing processes [Kreitler 1995].

There are some attempts to create complete computational models of manufacturing plants, in what is considered the new generation of digital manufacturing tools: the Digital Mock-Up (DMU) systems. QUEST/DELMIA [Systemes 2008], PROMODEL [Benson 1996], ARENA [Hammann and Markovitch 1995] are typical ex-

amples of these systems. They allow to design the 3D sceneries of industrial plants but they cannot cope with the collaborative issues and complexity of dynamic immersive visualization of the components operations.

In the literature, there are related works that treat the immersive visualization issues in Digital Manufacturing using Ray Tracing systems [Bigler et al. 2006]. However they process only static sceneries and at high computational cost. For instance, [Dietrich et al. 2005] proposes a visualization system using an Altix NUMAflex architecture that provides a low-latency, high-bandwidth inter-connect between the distinct nodes, gaining peak transfer rates of up to 6.4 GByte per second. [Wald et al. 2005] treats complex CAD design also using a very hard computational infrastructure.

In this work we propose a low cost solution for immersive collaborative visualization of manufacturing plants. The proposal suggests integration of different successful tools produced for specific areas of computer graphics: engines for interactive games, computer aided design packages, graphic editors, etc. Our proposal treats sceneries with dynamic components and allows collaborative interaction among geographically distributed players. Such methodology was implemented and validated through a case study associated with shipbuilding and offshore industries.

The paper is structured in five sections. Next section addresses the main challenges associated with immersive visualization of industrial processes as well as a group of existing solutions for its individual treatment. Section 3 details our integrated framework to the 3D manufacturing plant visualization, through aspects of modeling, conversion, visualization and interactivity stages. Then section 4 describes a group of experiments that were accomplished to validate the proposal. Finally, section 5 presents the conclusions drawn from the entire project.

2 VISUALIZATION OF PLANTS

The visualization process of dynamic manufacturing plants using VR resources includes a group of challenges and issues. From the conception of the virtual plant model and its simulation, to its actual use in collaborative immersive visualization, we enumerate the following main stages: i. Modeling; ii. Conversion (simplification); iii. Visualization; and iv. Interactivity.

Modeling: Such stage refers to the 3D plant digital model creation, through modeling all production process dynamics (workshops, workers, tools, equipments and their interaction). The following aspects are involved:

- Study and development of modeling techniques and simulation of production processes: such subject is target of study in different engineering areas. Plants simulation can be implemented through the use of commercial DMU tools that enable different visual quality levels. For instance, the developed models can be visualized as simple 2D structures or like complex dynamic sceneries with three-dimensional features and interactivity, in CAVE devices. The manufacturing plants models can incorporate very detailed CAD files, as result of mechanical projects of the processed products, as well as schemes of machines functioning and human behavior simulation (workers) of the assembly lines. The generated simulations can show 3D dynamics of the different process components;
- 3D Description Format: supposing that the immersive scenery will be obtained from DMU/CAD tools, many commercial DMU systems just allow the exportation of 3D sceneries in simple video formats as avi and mpeg. Others systems export in virtual environment description languages as VRML (Virtual Reality Modeling Language) [VRML 2008], however, these exported files are frequently very complex and non-optimized. So, due to the extensive set of exportation formats released by the different tools, and the peculiar needs for VR, the best options to provide an immersive distributed visualization of plants is still a challenge.

Conversion (simplification): Such stage includes issues related to

simplification of the 3D models generated in the modeling stage. Basically the following points must be treated:

- Definition of the attributes of the virtual model and the entities to be supplied to visualization API. Definition of virtual sceneries: to have a virtual 3D scenery, the geometric CAD design needs to be completed with information describing the appearance of objects (color, reflection characteristics, textures), the lighting environment, possible animations, interactions, sound, as well as behavior and functionality. Such definition can be done offline or applied during real time visualization;
- Reduction of the virtual model complexity. This issue is relevant in almost all VR applications, however it assumes larger importance on Digital Manufacturing. In this context, the DMU must be committed with the necessities VR optimizations. The variety of formats and the large number of geometric structures can make prohibitive the rendering scenery (as mentioned in section 1, in the case of the Boeing 777 airplane program, where more than 350 millions of individual polygons must be processed).

Visualization: Aiming a more realistic immersion, it is a good choice to adopt an engaging n walls multiprojection. Traditional techniques for multiprojection treatment make use of specialized systems that need complex hardware architectures. Some specific questions in multiprojection visualization should be studied:

- Keeping consistence of the projected entities states, their attributes and dynamic behaviors among the projections on the n walls;
- Synchronizing virtual clocks (logical timers) of the different physical system components, to aim the coherence of the dynamic sceneries visualization and its relationship with the displayed frame rate;
- Increasing the system performance related with the number of entities versus the number of projection walls.

Interactivity: The visualization processes should support different interactivity degrees. For instance:

- In manufacturing plants sceneries, the collisions treatment, the use of different devices for sensory perception of environment features (mouses, keyboards, joysticks, glasses, gloves, trackers, etc) are important factors that should be foreseen;
- A method of enabling the plurality of geographically distributed users to collaboratively view and interact have to be offered. Due to a large number of key players associated with modern manufacturing processes, methods and apparatus for virtual interactive sceneries, by multiple remotely-located users, are necessary.

Nowadays, there aren't any DMU tool able to treat all the stages and aspects mentioned above, nor a methodology that implement the modeling, conversion, etc, supplying the dynamic characteristics of the industrial processes to a collaborative visual system. However, many are the studies and techniques associated with each individual subject (modeling, conversion, etc). Several tools allow the design and exportation of static CAD plants models in formats that make possible the use of specialized systems to conversion CAD-VR. WalkInside [VRContext 2008] is one of these systems. There are also visual immersive systems developed for CAD models visualization as ENVIRON [Corseuil et al. 2004]. This system, when associated with VR tools, allows the CAD models visualization in VR environments.

Another possibility related to virtual environments is the use of game engines. There are game-development toolkits that provide means to create custom content and mission scenarios which facilitate idea generation and concept exploration with a short turnaround time [Fong 2006]. Some examples of these systems are Unreal Tournament [EpicGames 2004] and Quake [Quake 1997]. The former have partial open code and the last is a free and open-source software. Both provide graphics with high detail levels and

have high performance and robustness, supporting distributed geographic visualization. A modification of the Quake III engine together with the FreeVR [Sherman 2008] library have been used in the case study presented in section 4. Among the advantages of using the Quake III engine and the FreeVR library is they open-source licenses multi-platform capabilities.

3 A METHODOLOGY FOR IMMERSIVE VISUALIZATION

Based on the aspects mentioned on section 2, a methodology that enables a collaborative visualization of industrial processes was built. It takes, as input, 3D models obtained from commercial DMU tools, more precisely in applications evolving high complexity design and manufacture, such as the case for ships and offshore platforms construction [Kim et al. 2003]. Figure 1 shows an overview of our proposal.

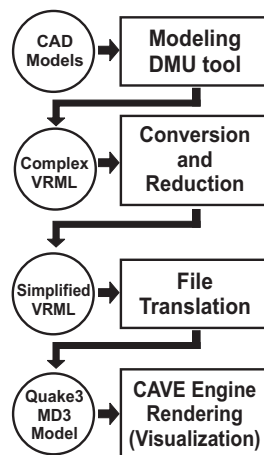


Figure 1: Methodology for collaborative visualization of industrial processes

Starting from CAD models, techniques of complexity reduction and conversion must be applied to obtain virtual sceneries, with their necessities components and attributes. It is proposed to visualize such sceneries in a multiprojection immersive environment, through an adaptation of the game engine Quake III Arena. Such engine can provide the necessary structure for attributes definition, rendering and multiprojection, as well as the needed interactive resources. The details of each one of the stages shown on the figure is described as follows.

Modeling: It is supposed that some DMU tool is being used to model the manufacturing process. Such tool may be able to export different CAD formats with animated entities, aiming to study the life-cycle, ergonomic aspects, among others, of the modeled objects.

Conversion: A dynamic model of the plant is obtained from the complete CAD project. This model can be described in a file, using different formats: DWG, VRML, ASE, DGN, etc. Due to the lack of commitment between the DMU tools and the visualization stage, such file have frequently excessive geometric information. Thus, it is needed a meshes complexity reduction tool to compose each element with the just necessary information. After trials with several alternative tools, like DeepExploration [Exploration 2008], 3DStudioMax [3DStudioMax 2008], OkinoPoliTrans [PolyTrans 2008] and VizUp [VizUp 2008], VizUp and 3DStudioMax was chosen.

The VizUp system can be used to reduce the number of existing polygons, in VRML files format, according to the wished visualization quality, in a manual way. The VRML file needs to be loaded in VizUp System and the user must choose an acceptable maximum rate of reduction of the VRML file that avoids the lack of reality of the model. This rate depends of each model.

After reduction, this VRML file needs an optimization and compatibilization with 3DStudioMax. DMU tools generate some no necessary informations for the immersive visualization system that need to be removed. It is important to emphasize that the 3DStudioMax just supports animated VRML in Interpolated mode. If VRML file is in Event mode a conversion must be done. Another point is that the VRML file generated by DMU treats each face of one object like a unique object. For example, the six faces of a cube are six different objects instead one unique object with six faces. Then, it is necessary to aggregate this faces in one unique object to optimize the VRML file.

Translation: Once the VRML is compatible and optimized, we need to set up the textures. The format used by Quake III Arena to describe objects and animations is the MD3. This format does not support color in objects, only textures, so it is necessary to recognize the colors of each object in the VRML file, create an image (bitmap) for each color and apply the texture in each object with their respective colors. In this way, VRML file has textures with the same colors of the objects, what does not change anything in his appearance, just makes possible a correct conversion to MD3 in the next step.

In the last step of conversion, 3DStudioMax is used to import and convert the already treated VRML file generated by DMU into a MD3 file. In this point the model can be simulated in the CAVE Quake. This conversion may take several minutes depending on the size and number of frames on the model.

Visualization: The stage of visualization and interactivity is accomplished by a game engine. We have used the Quake III game engine [Rajlich 2008] to solve the rendering, multiprojection and interactivity aspects. It is composed by some part of the game core, multiprojection code from FreeVR [Sherman 2008] and GtkRadiant [GtkRadiant 2008] sceneries editor, as shown at figure 2.

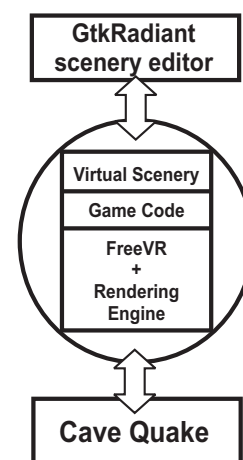


Figure 2: Modular structure of a Game Engine

The Quake Game Engine represents the virtual scenery using binary space partitioning (also known as BSP tree) structure for the surrounding ambient and MD3 structure for representing the models within this ambient. Each model may have its general attributes, which are passed as flags inside the MD3 structure, and its particular attributes, which are passed in each reference to MD3 structure, in the BSP. This allows easy customization. All the game rendering process is done using the cross-platform graphical API OpenGL. The engine chooses what should be drawn, by looking in the BSP structure, and sends it to OpenGL. The collision detection is also done by the game engine.

The multiprojection visualization code is all done by FreeVR, an open-source virtual reality interface/integration library. It has been designed to work with a wide variety of input and output hardware, with many device interfaces such as gloves and head-mounted display (HMD). The library allows n-walls multiprojection and the adjustment of each projection wall, in accordance with the CAVE

morphology. The necessary modifications to create projections out of the axis are read as parameters from a configuration file.

GtkRadiant is the most used Quake scenery editor. It allows to apply and modify the outputs of Quake, such as illumination, texture and interactivity of components/objects. This editor can import files in some formats such as static models ASE and MAP and animated models in MD3.

4 CASE STUDY

The proposed methodology was validated in a case study on Shipbuilding and Offshore Industry, as described below.

As typical large industrial conglomerates, the Shipbuilding and Offshore Industries use DMU technologies. DELMIA, CATIA, ENOVIA, QUEST and PROCESS ENGINEER are important toolsets for Product Life-cycle Management (PLM). For instance, DELMIA [Systemes 2008] is widely used in aerospace and shipbuilding industries and allows to optimize the factory layout; to determine and validate assembly sequences and ergonomics aspects; and to make possible global analysis and 3D simulation. QUEST presents a large set of resources that includes analysis and simulation of resources and process flow; layout analysis; etc. However, the 3D sceneries created by all these systems cannot be directly visualized in a multiprojection way.

Thus, starting from CAD plants of ships and platforms, as well as from digital model of a shipyard, in this case generated on DELMIA and QUEST [Systemes 2008], below we show the performance of the engineering solution proposed.

Adopting the stages presented in section 3, it is pointed out the details used in the case study.

Modeling Stage. In the modeling stage, the different CAD projects were integrated in a 3D virtual scenery. We have tested three different complexities sceneries, called *Model₁*, *Model₂* and *Model₃*, with the characteristics showed in table 1.

Model	Vertexes	Triangles	Storage (Kb)
<i>Model₁</i>	81,720	53,796	11,033
<i>Model₂</i>	62,372	55,794	6,958
<i>Model₃</i>	76,972	61,266	21,991

Table 1: Complexity of the models

Conversion Stage. Starting from the VRML exported sceneries it is achieved the models complexity reduction, in order to reach a good visual quality and to control the number of polygons. For this, as above, it is used Vizup. Different percentages of reduction were applied. Table 2 shows the reduced models of *Model₁*.

With a reduction rate of up to 50 percent it was still possible to identify the model, but with loss of details. The ideal reduction rate for *Model₁* was around 44 percent.

Reduction (%)	Vertexes	Triangles	Storage (Kb)
50	60,202	26,898	10,254
48	61,277	27,973	10,305
46	62,349	29,049	10,354
44	63,425	30,125	10,402

Table 2: Complexity of the reduced models of *Model₁*

The *Model₂* and the *Model₃* had presented the best parameters shown in table 3, after appropriated reduction.

From the tables we can conclude that the reduction is really efficient for complex models with large amount of information. In models where the complexity is smaller it is not possible to apply high reduction rates. Due to simplicity already existing in small models, high reduction rates produce loss of quality at visualization process.

Once the models are converted into a reduced VRML file, some of their components attributes are manipulated through 3DStudioMax. The animated components are separated from the static components

and the texture characteristics should be individually observed in order to verify the quality acquired from CAD models, and then possibly improved.

Visualization Stage. After modeling and conversion, the obtained scenery can be visualized in a multiprojection way. The methodology proposed allows projections among n screens. It was used a V-CAVE with two walls (see figure 3) to validate the proposal. Also different sceneries description formats, other than VRML, may be used as input of the system, reassuring its portability. The multiprojection system implemented by CaveQuake was shown efficient and simple. Just some adjustments must be done in the configuration parameters so that the correct projections in a V-CAVE can be obtained. Rendering rates were measured with the three models and all of they were around 100 fps.

In order to verify scalability of the proposal, the rendering rates were tested with four walls of projection. One more graphic card with two outputs was used and the rates of rendering remained at the same level.

Testing related to geographic distribution have been released, considering it is a feature of Quake duly established.

Some other issues were tested. For example, the CaveQuake obstacles treatment, that was showed adequate.

A picture of the V-CAVE used for the experiments can be observed in the figure 4.

Model	Reduction(%)	Vertexes	Triangles	Storage (Kb)
<i>Model₂</i>	49	46,739	28,461	6,197
<i>Model₃</i>	58	53,882	25,731	20,954

Table 3: Complexity of the reduced models of *Model₂* and *Model₃*

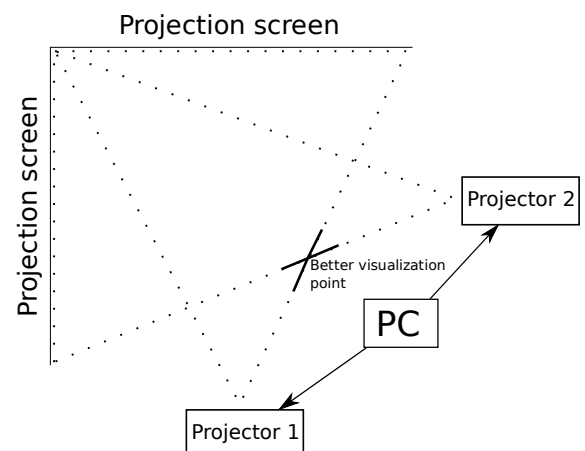


Figure 3: CAVE Layout (V-CAVE)

5 CONCLUSION

Digital manufacturing technologies are being used in many industrial production process. It is specially adopted on modeling and simulation of the manufacturing processes in large industrial conglomerates. Although the visualization of CAD projects is already a practice in these contexts, the use of advanced 3D immersive interfaces using VR resources is still a challenge.

In this work we have proposed a methodology to support collaborative multiprojection visualization of manufacturing processes.

It was proposed to start with dynamic plants obtained from scenery models supplied by DMU tools. After identifying the limitations, restrictions and needs associated with the visualization problem, a group of procedures that enables the projections in n walls, with immersive features and VR resources, integrating different existing tools, was proposed.

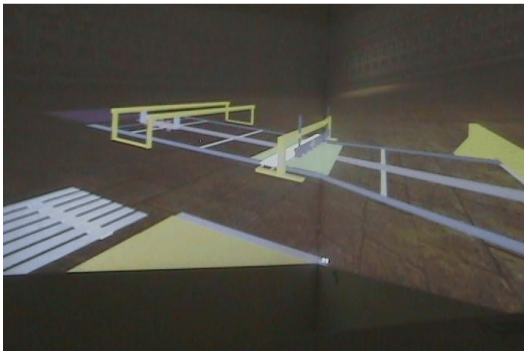


Figure 4: Multiprojection visualization of scenery in V-CAVE.

The engineering solution was validated in an actual application associated with the naval and offshore industry. Sceneries related to the plants of shipyards, ships and platforms were modeled, converted and visualized in centralized and collaborative environments.

The accomplished conversions and the use of Quake III game engine were proved efficient, concerning the scalability, heterogeneity, portability, rendering and multiprojection issues.

The complexity reduction along the conversions allowed the use of VR resources in real time visualization.

The proposed methodology can be applied directly in the plant by naval technicians with no need for specialized programming knowledge.

The solution using Quake III game engine is a significant low cost implementation solution.

As future perspectives, it is necessary to improve and expand the automation level associated with some stages of the methodology, such as the conversion and translation stages.

As a future work, it is necessary to obtain solutions for supporting a better interoperability between models (ontology), perhaps in phase with STEP standard [ISO10303 1994].

Finally, it must be improved some interactivity aspects as inclusion of mixed reality resources to Quake, enabling the visualization of either workers or machines, in real or virtual way, and their interaction.

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