A GENERAL PURPOSE CAVE-LIKE SYSTEM FOR VISUALIZATION OF ANIMATED AND 4D CAD MODELING

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ABSTRACT

In the last decade, virtual reality (VR) systems have been used to enhance the visualization of CAD projects. The immersive VR techniques allow to the designer interacting and modeling in a more intuitive and efficient way. Current 4D and animated simulation CAD tools are a new challenge for immersive visualization. In this paper we propose a general purpose cave-like system that enables interactive visualization of 4D and animated CAD models. In an automated way, the system is able to treat static and dynamic 3D environments, allowing to share the experience of navigation in the scene among the users, even geographically distributed. The collaborative immersive multi-projection visualization approach has basically four modules for modeling, converting, visualizing and interacting. Besides the system had be designed and implemented for visualization of CAD models, it can be used for general purposes thanks to the use of a XML-based format on the visualization module. The system proposed is validated through a case-study using dynamic 3D models created on digital manufacturing softwares of Shipbuilding and Offshore Industries.

KEY WORDS: Immersive modeling, Virtual Reality, Digital Manufacturing and Shipbuilding and Offshore Design

1 – Introduction

Large and high-end engineering projects such as automotive, aerospace and shipbuilding are already engineered almost entirely digital. Their complexity demands assembly simulations through the use of mock-ups to simulate the several stages of the production process. These physical mock-ups have a very complex and high cost design. So, digital 3D mock-ups are good alternatives.

Digital manufacturing is an initiative to define every characteristics of the design-to-manufacture process, enabling simulations and 3D digital mock-ups. It allows manufacturers in any industry to virtually define, plan, create, monitor and control all production processes.

Systems for digital manufacturing must support multiple aspects, including product design, analysis, manufacturing, data sharing and communication, among others, relying on advanced technologies such as CAD, CAE, real time 3D simulations, CAM, Product Data Management Systems (PDM), Computer Aided Process Planning (CAPP), Digital Enterprise Technology (DET) etc [1].

In practice, however, the digital design is not as simple as it might first seem. Several challenges and issues are involved, for instance:

- In such processes a large number of concurrently working design teams are involved. For instance, in the case of the Boeing 777 airplane project, more than 230 geographically dispersed groups had to be coordinated.
- Eminent problems in large-scale manufacturing arise from the difficulty in properly fitting all individual components together in a final product.
- 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 departments. 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 [2].
- If in the past decades digital manufacturing systems were focused in the static product design (visualization of the CAD project of the product), nowadays it is state of the art to focus on the modeling and simulation of dynamic manufacturing plants as a whole process. Digital mock-up systems must analyze animated CAD designs associated with the production process cycle, the ergonomic of the workers, the localization and performance of the machines and the assembly steps.
- Extending the traditional planning tools, visual 4D models combine 3D CAD models with construction activities to display the progression of construction over time. 4D visualization tools need to deal with complex time simulation files.

Thus, due to the complex and distributed nature of recent high-end engineering projects, the possibility of virtual, interactive and collaborative immersive visualization of whole production process and 4D analysis have become an important issue which can determine a company/consortia success [3] [4].

In this context, Virtual Reality (VR) techniques can provide an interactive high-quality visualization solution for evaluation of the full animated 3D/4D CAD design and the whole manufacturing process [5].

Virtual Reality techniques make 3D/4D visualization of industrial scenarios possible, offering a realistic and interactive interface for different production stages and processes, aiming at anticipating problems like overlaps of assembly parts, obstacles collisions, risky situations, etc. These techniques include several levels of interactivity and immersive technologies.

CAVE devices [6], for instance, are room-size VR display systems. In these systems the generated images are distributed among computers and multi-projected onto several walls. Each individual projection contains a part of the total scenario, 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 it possible to increase the immersion and interactivity degrees associated with the scenarios use of such configuration makes it possible to increase the immersion and interactivity degrees associated with the scenarios [7] [8].

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.

In this work an approach on immersive collaborative visualization of 4D and animated CAD production process is proposed. It allows the use of geographically distributed CAVEs, called a multi-CAVE. Remote players can navigate and interact through 4D/3D dynamic plant scenarios in a multi-CAVE. During the navigation, the players can exchange information in order to cooperatively solve the observed problems.

The proposal deals with 3D/4D scenarios with dynamic components and allows collaborative interaction among geographically distributed players. It is suggested an integration of different techniques: *i* a reduction and conversion stage able to convert different 3D/4D models of the plants into VR dynamic scenarios, *ii* a rendering and visualization real time module that displays the scenarios into *n* walls and *iii* an interactivity multi-CAVEs stage that allows a distributed collaboration among several players. Such approach was validated through a case study associated with shipbuilding and offshore industries.

The paper is structured in five sections. The next section addresses the main challenges associated with immersive visualization of industrial processes as well as a group of existing solutions to deal with specific sub-problems. Section 3 details the integrated framework for the 3D/4D manufacturing plant visualization, through aspects of modeling, conversion, visualization and interactivity stages. 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 Industrial Plants

The use of digital manufacturing techniques can reduce cost, complexity and time associated with the production 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 [9] [10].

However, the collaborative multi-CAVE visualization process of 4D and animated dynamic manufacturing plants using VR resources introduces a new group of challenges and issues. From the conception of the virtual plant model and its simulation, to its actual use in collaborative immersive visualization, the following main stages are enumerated: *i*. Modeling; *ii*. Conversion and Reduction; *iii*. Visualization; and *iv*. Interactivity and Collaboration.

Modeling: Such stage refers to the 3D/4D plant digital model creation, through modeling all production time process dynamics (workshops, workers, tools, equipments and their interaction). The following aspects are involved:

- Study and development of modeling techniques and simulations of production processes is subject of study in different engineering areas. Plants simulation can be implemented through the use of commercial Digital Mockup Systems (DMU) that enables different visual quality levels. For instance, the developed models can be visualized as simple 2D structures or like complex dynamic temporal scenarios with 4D features and interactivity. 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, as well as, 4D temporal simulation. Digital mock-up systems like QUEST and DELMIA [11], PROMODEL [12], ARENA [13] are typical examples of these systems. They allow one to design the 3D/4D scenarios of industrial plants but they cannot cope with the collaborative issues and complexity of dynamic immersive visualization of the components operations.

- Choice of a 3D description format. Supposing that the immersive scenery will be obtained from DMU or CAD tools, the fact that many commercial DMU systems just allow the exportation of 3D scenarios in simple video formats such as *avi* and *mpeg* has to be taken into account. Some systems export in virtual environment description languages as VRML (Virtual Reality Modeling Language) [14], but these exported files are frequently very complex and non-optimized. So, due to the extensive number of exported formats by the CAD tools, and the special needs for VR, the best choice to provide an immersive distributed visualization of animated industrial plants is still a challenge.

Reduction and Conversion: Such stage includes issues related to conversion and simplification of the 3D models generated in the modeling stage. Basically the following points must be deal with:

- Definition of the virtual model attributes and the entities to be supplied to visualization API. To have a virtual 3D scenario the geometric CAD design must be completed with information describing the appearance of objects (color, reflection characteristics, textures), the lighting environment, interactions, sound, as well as behavior and functionality. Such definition can be done off-line 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 have the necessaries VR optimizations. The variety of formats and the large number of geometric structures can make prohibitive the rendering of the 4D animated scenarios. For instance, in the case of the Boeing 777 airplane program, more than 350 million individual polygons must be processed.

Visualization: There are related works that deal with several issues associated with 3D visualization [4]. However aiming at a more realistic immersive visualization, it is a good choice to adopt an engaging *n* walls multi-projection. Traditional techniques for multi-projection handling make use of specialized systems that need complex hardware architectures [2] [5]. Some specific questions in multi-projection visualization should be studied:

- Maintaining consistence of the projected entities states, their attributes and dynamic behaviors among the projections on the *n* walls;
- Synchronizing virtual clocks (logical timers) of different physical system

components, aiming at the coherence of the dynamic scenarios visualization and its relationship with the displayed frames rates;

- Increasing the system performance, considering the number of entities to be projected versus the number of projection walls.

Interactivity and Collaboration: The visualization process should support different interactivity degrees and collaboration. For instance:

- In visualization of manufacturing plants scenarios, the use of different devices for sensory perception of the environment features (mouses, keyboards, joysticks, glasses, gloves, trackers, etc) are important factors that should be foreseen;
- A method that enables users to collaboratively view and interact has to be offered. They must consider the use of geographically distributed multi-CAVEs devices.

Nowadays, no DMU tools are able to deal with all the stages and aspects mentioned above. Similarly, no methodology/system that implements the modeling, conversion, etc, is able to provide the necessary characteristics to industrial processes through a collaborative visual system. There are, however, many studies and techniques regarding each individual subject (modeling, conversion, etc). Several tools make the design and exportation of CAD models possible allowing specialized systems to convert these CAD projects to VR solutions. WalkInside [15] and Division Reality [16] are some of these systems. There are also visual immersive systems developed for CAD model visualization, like VRJuggler [17], Viral [18] and ENVIRON [19], which, when associated with VR tools, allow CAD models visualization in VR environments.

Another possibility related to virtual environments is the use of game engines. Some examples of these systems are Unreal Tournament [20] and Quake [21] which provides 3D graphics with high detail levels. Both have high performance and robustness, supporting distributed geographic visualization. The implementation used in this work is based on the Quake III Arena [21] engine code with the FreeVR [22] library, both under open-source license. Others works that have used this kind of engines include [23] [24] [25] [26] [27] [28].

3 – An Automated Platform for Immersive Visualization

Based on the aspects mentioned on section 2, an automated platform that enables a collaborative visualization of industrial processes was built. It takes as input animated 3D/4D models obtained from commercial DMU tools, more precisely models of manufacture processes with high complexity design, such as ships and offshore platform constructions [29]. It considers some existing techniques and tools which, integrated, should present the characteristics described below.

- Heterogeneity: the quality and consistency of the visualization process should be guaranteed, regardless of the different hardware platforms used;
- Scalability: the performance of the system should be independent from the number of walls and CAVES used in the multi-projection devices;
- Portability: the methodology can be applied to different projection hardware and software types, as well as different standards and data formats of the files;
- Collaboration: the system must provide a geographically distributed visualization, navigation and collaboration;

FIGURE 1 shows an overview of the work's proposal. Starting from animated 3D/4D DMU files, techniques of complexity reduction and conversion must be applied to obtain virtual scenarios, with their necessary components and attributes. A system to visualize such scenarios in a multi-projection immersive environment is proposed. Such system can provide the necessary structure for attributes definition, rendering and collaborative multi-projection, as well as the needed interactive resources. The details of each one of the stages shown on the figure is described as follows.

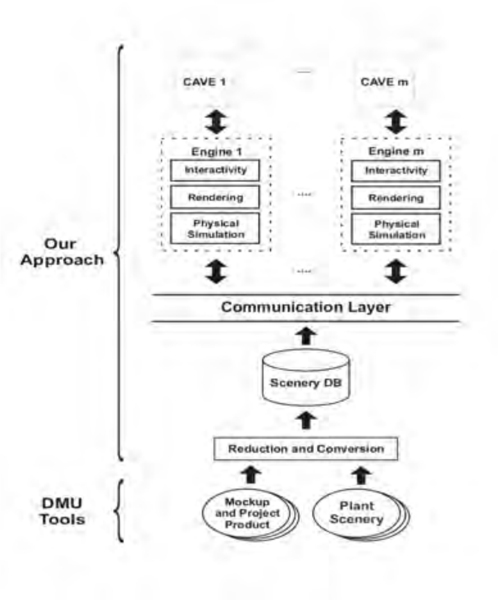

Figure 1: Platform for collaborative visualization of industrial processes

Modeling: It is supposed that some DMU tool have been used to model the manufacturing process. Aiming to visualize dynamic scenarios, such tool must be able to export 3D/4D sceneries with animated entities, allowing the study of the involved production aspects of the modeled objects.

Reduction and Conversion: DMU tools are not equipped with VR immersive devices and practices. Frequently these systems supply 3D scenarios with a great amount of unnecessary details to the VR visualization. The approach here has a reduction and a conversion layer that receives as input a VRML format of scenario[1]. This layer analyses the input VRML file, achieving the following procedures:

- aggregation of shapes that share color and attributes and compound the same object.
- verification of the animation procedures, transforming the event animation VRML approach to interpolated approach.
- remotion of the unnecessary animation information associated with static objects.

Thus, this stage reduces the complexity of the objects to obtain each entity with just the necessary information. The final VR model is then recorded in a XML-based format with reduced complexity.

Visualization: From the XML description, a visual system for rendering and multi-projection was developed (see FIGURE 2). The system displays the virtual XML scenario using binary space partitioning (BSP) structure.

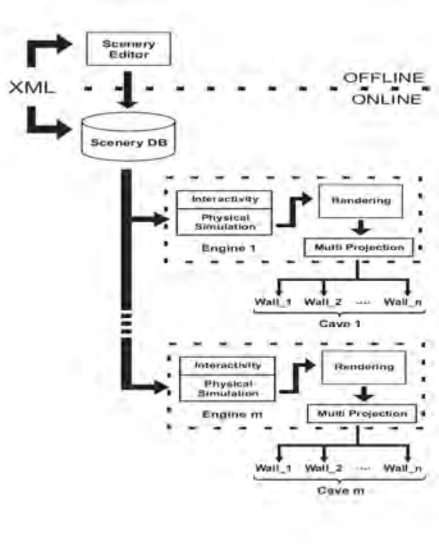

Figure 2: Modular structure of our system

1Others 3D formats, like DWG, ASE, DGN, etc, can be converted into VRML using conversion tools like Deep Exploration [30], 3DStudioMax [31] and OkinoPoliTrans [32]

The collision detection is done by the *bounding box* technique. The multi-projection visualization code is based on FreeVR [22], 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). This system allows *n*-walls multi-projection and the adjustment of each projection wall, in accordance with the CAVE morphology.

The system can be used by project designers without computer knowledge. Those steps that involve some interaction with the user, such as addition of optional editing features, were customized and the details documented, in order to be also operated by people without expertise in computing.

4 – Case Study

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

Like other large industrial conglomerates, the Shipbuilding and Offshore Industry uses DMU technologies. DELMIA, CATIA, ENOVIA, QUEST and PROCESS ENGINEER are important toolsets for Product Life-cycle Management (PLM). For instance, DELMIA [11] is widely used in aerospace and shipbuilding industries. This tool allows optimization of the factory layout; to determine and validate assembly sequences and ergonomics aspects; and to make possible global analysis and 3D temporal simulation. QUEST presents a large set of resources that include analysis and simulation of resources and process flow; layout analysis; etc. However, the 3D/4D scenarios created by these systems cannot be directly visualized in a multi-projection way.

Thus, starting from CAD plants of ships and platforms, as well as from animated digital model of a shipyard, generated on DELMIA and QUEST, the engineering solution proposed can produce collaborative multi-projection visualization of industrial building process, in immersive environments.

Adopting the stages presented in section 3, the details used in the case study are pointed out below.

Modeling Stage: In the modeling stage, the different CAD projects were integrated in a 3D virtual scenery through DELMIA and QUEST [11]. FIGURE 3 presents a shipyard workshop (real scenery) and the correspondent model (virtual scenery) developed with these tools.

Figure 3: Real scenery and virtual scenery model.

Three different complexities animated scenarios, called with eighty thousands of vertices, with five hundred thousands of vertices and with three million of vertices, were tested and exported to VRML format, with the characteristics shown in TABLE 1. They originated from the scenery of a paneling line showed in FIGURE 3. In that scenery the panels are moved from station to station, in a temporal dynamic way.

Model	**Shapes**	**Animated Objects**	**Storage (Kb)**
Model1	13,150	967	10,136
Model2	66,484	100	52,342
Model3	503,426	732	389,411

Table 1: Complexity of the models

Reduction and Conversion Stage: Starting from the VRML exported scenarios, the models complexity reduction and conversion was achieved. From a number of initial shapes the reduction technique gets to reduce a very small final number of objects. The number of final animated objects is reduced and they compose a new scenery where the animated objects are converted into an interpolated dynamic frames. TABLE 2 shows features of the reduced and converted models of the scenarios. From the tables it can be concluded that the reduction is really efficient.

Model	Shapes	Animated Objects	Storage (Kb)
Model1	993	632	4,085
Model2	2218	10	37,580
Model3	2934	154	286,355

Table 2: Complexity of the reduced models

Visualization Stage. After modeling and conversion, the obtained animated scenario could be visualized in a multi-projection way. The platform allows a multi-cave projection, each cave using *n* screens. Our implementation is based on the Quake III [34] adapted game engine. Initially, it was used a V-CAVE with two walls (see FIGURE 4) to validate the proposal. Also different scenarios description formats, other than VRML, may be used as input of the system, reassuring its portability.

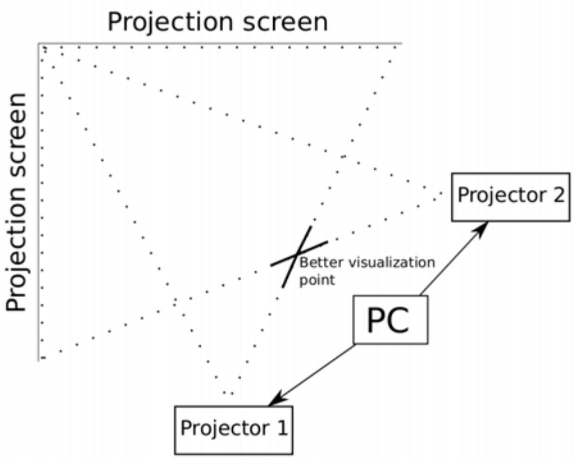

Figure 4: CAVE Layout (V-CAVE)

In order to prove the portability between different kind of hardware, the visualization process was realized in a multi-projection system with two planes and also with a special television with 3D stereo support. In the test with the television, we used an active stereoscopic glasses to allow the use of stereoscopic feature. This greatly increased the sense of realism of the scene. Both multi-projection and television test implemented was portrayed as efficient and simple. Rendering rates were measured with the three models, 70 fps for the first, 30 fps for the second and 10 fps for the third. In order to verify scalability of our 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. Tests related to geographic distribution was conducted and the suitability of the platform for this purpose was proved. For this, we used one engine for each of the *m* geographically distributed hosts. Some other issues were tested, for example, the collision treatment that was portrayed as adequate, too.

A picture of the V-CAVE used for the experiments and television test can be observed in the FIGURE 5.

(a) A CAD model being visualized in V-CAVE.

(b) Another CAD model being visualized in the television.

Figure 5: V-CAVE and television tests.

5 – Conclusion

Digital manufacturing technologies are being used in many production process stages. It is specially adopted on modeling and temporal and spatial 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/4D immersive interfaces using VR resources, capable of integrating a range of design tools, is still a challenge.

In this work we proposed a methodology to support collaborative multi-projection visualization of manufacturing processes. It is proposed to start with dynamic animated plants obtained from scenarios models supplied by DMU tools.

After identifying the limitations, restrictions and needs associated with the target problem, a group of procedures that enable the multi-cave projections, with immersive features and VR resources, integrating different existing tools, was proposed. The methodology was validated in an actual application associated with the naval and offshore industry. Scenarios related to the animated plants of shipyards, ships and platforms were modeled, converted and visualized in centralized and in collaborative multi-cave environments.

The accomplished reduction, conversions, visualization and interactive system were proved efficient, concerning the scalability, heterogeneity, portability, rendering, multi-projection multi-cave issues and cost. 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 people with no need for specialized programming knowledge.

Future efforts will be directed at obtaining solutions for supporting a better interoperability between models (ontology), perhaps in phase with STEP standard ISO 10303 [35]. Finally, some interactivity aspects such as the inclusion of mixed reality resources to the system, enabling the visualization of either workers or machines, in real or virtual way, and their interaction must be improved.

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