A Virtual Reality Computing Platform for Real Time 3D Visualization

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Abstract. In the last decade, virtual reality (VR) systems have been used to enhance the visualization of design projects. The VR techniques allow to the designer interacting and modelling in a more intuitive and efficient way. Current 3D and animated simulation tools are a new challenge for 3D visualization. In this paper we propose a general VR computing platform that enables real time visualization of 3D scenarios for manufacturing and forensic simulations. The platform 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 platform proposed is validated through a case study using real time 3D models manipulations and interaction in a simulated car crash.

Keywords: Virtual Reality (VR), CAVE, Real Time programming.

1 Introduction

There is a popular quote: *"Before anything can happen in the real world, first it must happen in the imagination; the world of dreams and possibilities"*. Sometimes, it is mandatory to be aware from special situations before they happen in the real world. This is the case of abrupt and unpredicted situations like environmental changes, illness problems and, auto, aerospace and naval accidents.

By creating an environment which simulates a potentially harmful real-life situation could help with these issues. The interactive scenario removes these concerns and help the user gain a knowledge and understanding of the subject matter without being put into a costly or harmful environment.

The design of robust advanced systems for unpredicted control situations is the corner stone of modern simulation theory and systems. Several challenges and issues are involved, for instance:

- In such processes a large number of concurrently unpredicted facts are involved. For instance, in the case of an airplane crash, the data fields of the accident database must cover a multitude of parameters including aircraft, weather conditions, and flight as well as airport characteristics.
- Eminent problems in large-scale simulation arise from the difficulty in properly fitting all individual components together in a final product.

If in former times digital simulation systems were focused in the static representation of past situations, nowadays it is state of the art to focus on modelling and simulation of complex dynamic systems that characterized by information uncertainty of model structures and control goals, a high degree of freedom and essential nonlinearities, instability, distributed sensors and actuators, high level of noise, abrupt jump changes in structure and dynamics.

Virtual reality is used to create interactive scenarios which reflect real-life situations, simulating the way equipment responds; emulating the way machinery works or replicating soft skills such as human actions and behaviour. Complicated pieces of equipment, processes or systems can be recreated using a number of techniques. This form of e-learning allows users to learn about mechanisms and processes that would be physically or logistically difficult to do so in other conditions.

In practice, while VR systems can be regarded as human interaction with dynamic computer-generated virtual environments in real time, a VR system design is not as simple as it might first seem. Research on virtual reality started from input devices, hardware interfaces, simple applications, to system infrastructure, more input and output channels, and sophisticated applications. The researches on virtual reality have become very popular. With different degrees of reality, many systems were developed. Desktop VR system achieves a little VR effect with a fixed screen. Head Mounted Display (HMD) and BOOM achieve VR with a small display, which is close to viewer's eyes and moves with him. Immersive VR uses projection-based screens, which are fixed and distant from the viewer to form virtual environments [24, 2]. The degree to which a system deals successfully with above difficulties depends on the computing platform of such advanced system.

Thus, due to the complex and dynamic nature of these real-life situation projects, the possibility of virtual, interactive and collaborative immersive visualization of whole simulation process and 3D analysis have become an important issue which can determine a project success [14, 9, 22].

In this work an approach on a computing platform for immersive collaborative visualization of 3D and dynamic system is proposed. It allows the use of geographically distributed VR media, called a multi-VRmedia. Remote players can navigate and interact through 3D dynamic scenarios in a multi-VRmedia. During the navigation, the players can exchange information in order to cooperatively solve the observed problems.

It is suggested an integration of different VR techniques to get a final distributed collaboration among several players. Such approach was validated through a case study associated with traffic accidents at real scenarios.

The paper is structured in five sections. The next section addresses the main challenges associated with the simulation of unpredicted control situations and enumerates a group of existing solutions to deal with specific subproblems. Section III details the proposed computing platform for the 3D/4D manufacturing/forensic visualization, through aspects of modeling, simulation, visualization and interactivity stages. Section IV describes a group of experiments that were accomplished to validate the proposal. Finally, section V presents the conclusions drawn from the entire project.

2 Real-life Situations Simulation

The simulation of unpredicted control situations can reduce cost, complexity and time associated with the understanding and knowledge acquisition process needed for the real-life problem solution. Moreover, virtual reality enables to view the competency of users, see the decisions they make and how they then react to the consequences. 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 [15, 6, 5, 4]. However, the collaborative multi-visualization process of 3D and dynamic systems using VR resources introduces a new group of challenges and issues.

From the conception of the virtual model and its simulation, to its actual use in collaborative immersive visualization, the following main stages are enumerated: i. Modeling & Simulation ii. Visualization; and iii. Interactivity and Collaboration.

- Modeling and Simulation. The modeling stage refers to the 3D situation digital model creation, through modeling all situational time process dynamics (workshops, workers, tools, equipments and their interaction).
  Study and development of modeling techniques and simulations of situational processes is subject of study in different engineering areas. Some models can be implemented through the use of commercial Digital Mockup Systems (DMU) like QUEST and DELMIA, PROMODEL, ARENA [5, 4, 11] that enable different visual quality levels. For instance, the developed models can be visualized as simple 2D structures or like complex dynamic temporal scenarios with 3D features and interactivity. They allow one to design the 3D scenarios but they cannot cope with the collaborative issues and complexity of dynamic immersive visualization of the components operations.
  The modelling phase implies de definition of the virtual model attributes and the entities to be supplied to visualization API. To have a virtual 3D scenario the geometric 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.
  The generated simulations must show 3D dynamics of the different process components, as well as, 4D temporal simulation. Simulation must be consistent with the real scene matching physical conditions and assumptions for the accuracy of resulting simulation.
- Visualization. There are related works that deal with several issues associated with 3D visualization [12, 20, 19, 10]. However aiming at a more general immersive visualization, it is a good choice to adopt an engaging n

multi-virtual reality projection. Traditional techniques for multi-projection handling make use of specialized homogeneous systems that need complex hardware architectures [6, 23]. Some specific questions in multi-visualization should be studied:
  - Maintaining consistence of the projected entities states, their attributes and dynamic behaviors among the projections on the n nodes;
  - 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 nodes.
- Interactivity and Collaboration. The visualization process should support different interactivity degrees and collaboration. For instance:
  - In visualization of unpredicted control situations 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-virtual reality 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, simulation, etc., is able to provide the necessary characteristics to manufacturing/forensic processes through a collaborative visual system. There are, however, many studies and techniques regarding each individual subject (modeling, simulation, etc).

Several tools make the design and exportation of CAD models possible allowing specialized systems to convert these CAD projects to VR solutions. WalkInside [22] and Division Reality [17] are some of these systems. There are also visual immersive systems developed for CAD model visualization, like VRJuggler [1], Viral [21] and ENVIRON [7], 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 [8] and Quake [18] which provide 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 OGRE [16] engine code with the BULLET [3] physics library, both under open-source license.

3 A Computing Platform for Immersive Visualization

A computing platform includes a hardware architecture and a software framework (including application frameworks), where the combination allows software, particularly application software, to run. Typical platforms include a computer's architecture, operating system, programming languages and related user interface (run-time system libraries or graphical user interface).

Figure 1 shows an overview of the work's proposal. A system to visualize scenarios in a multi-virtual reality media environment has been defined. Such system will provide the necessary structure for attributes definition, rendering and collaborative multi-visualizations, as well as the needed interactive resources.

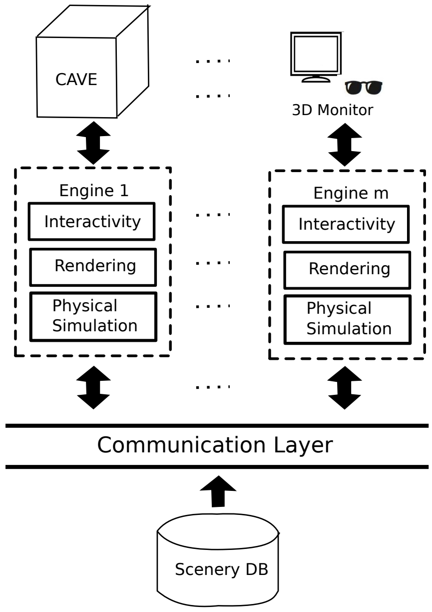


Fig. 1. Platform for Collaborative Visualization

Based on the aspects mentioned, an automated platform that enables a collaborative visualization of unpredicted situation processes 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 VR resources used in the virtual reality nodes;
- Portability: the methodology can be applied to different projection hardware and software types.
- Collaboration: the system must provide a geographically distributed visualization, navigation and collaboration.

The distributed multiple-display virtual reality hardware components used in this work are Desktop, Head Mounted Display (HMD) and CAVE virtual reality resources. Fig. 2 depicts the projection structure of the implemented PC-based CAVE system, which is a $3 \times 3 \times 2.5\ m^3$ surround screen projection system. The hardware components of the PC-based CAVE system are described as follows:

– Personal computers (PCs) - five PCs for driving the system. One is server for receiving input signals; the others are clients for screen display.
– Projectors - four high bandwidth stereo projectors.
– Signal sync devices - the signal sync devices are used to synchronize the RGB signals from client PCs.
– Stereo vision - shutter glasses and other peripherals (emitters, wiring, etc) needed to operate them properly.
– Viewing point tracking device - a viewing point tracking device (one transmitter, two receivers) with an extended range controller (ERC).
– 3D Wand - 6-DOF hand-held input device.
– Screen/projection surface, supporting structure, cable, EPC2, ELR, etc.

PC connectivity of the PC-based CAVE system is depicted inf Fig. 2 and stablished according to [13]. A software package was developed to drive the PC-based CAVE system.

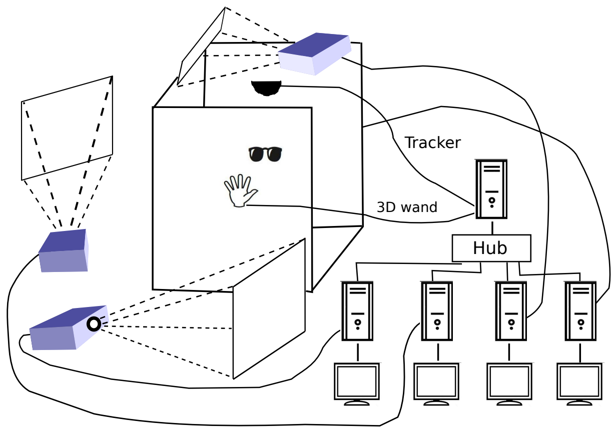


Fig. 2. CAVE Structure

In graphics-based virtual reality applications, the complexity of the modeled virtual worlds dominates the rendering performance of systems. A virtual reality system can be separated into three parts - input, computation, and output. The input part consists of reading tracking devices and wands; the computation part includes any computation of the virtual world and management of the world database; the output part consists of immersive screen displays.

The details of each one of the virtual reality nodes shown on figure 1 is described as follows. From a XML description, a visual system for rendering and multi-visualization was developed (see figure 3). The system code is based on OGRE [16], an open-source rendering engine. 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 system allows n-walls multi-projection and the adjustment of each projection wall, in accordance with a CAVE morphology.

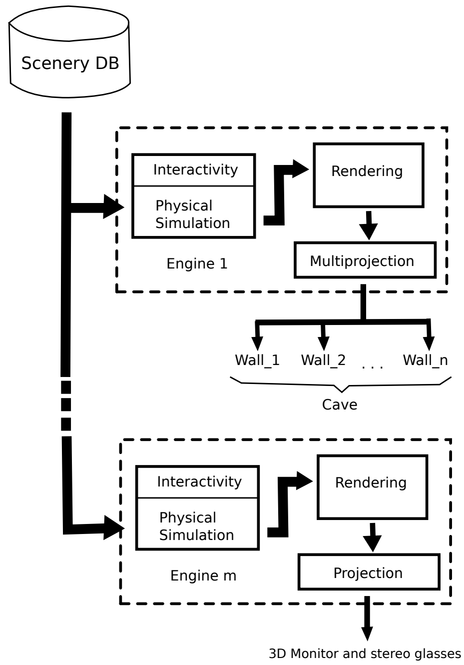


Fig. 3. Modular structure

The system could be used by project designers without computer knowledge. Those steps that involve some interaction with the user must be customized and the details documented, in order to be also operated by people without expertise in computing.

Currently, there are several languages and tools that enable the creation of virtual scenarios. However, existing approaches are not intuitive and require a thorough knowledge of the user. The proposed framework relies on the utilization of a generic metadata for the description of virtual scenarios which can be applied by different tools for authoring, and which can facilitate the subsequent automatic generation of OGRE code. With this approach OGRE developers can focus on the codification of the dynamics and strategies of the application being developed which helps reducing considerably the development time of these applications.

4 Case Study

The proposed platform was validated in a case study on car crash simulation. This tool allows optimization of manufacturing layout problems; to determine and validate assembly sequences and ergonomics model aspects; and to make possible global analysis and 3D temporal simulation.

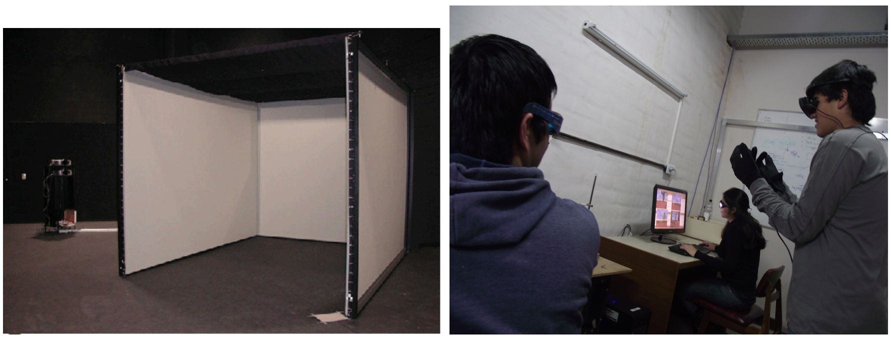
Adopting the stages presented in section 2, the details used in the case study are pointed out below. In the modeling & simulation stage, different 3D models were integrated in a 3D virtual scenery. The system displays the virtual XML scenario using binary space partitioning (BSP) structure. The collision detection and physics simulation was done by BULLET as physics library [3] and *bounding box* technique.

After modeling and simulation programming, the obtained animated scenario could be visualized in a multidisplay way. The platform allows a multi-VR media projection, each node using their own resources. Our implementation is based on the OGRE [16] adapted game engine. Initially, it was used a special monitor with 3D stereo support to validate the proposal (see figure 4(b)). In the test with the monitor, we used active stereoscopic glasses to allow the use of stereoscopic feature. This greatly increased the sense of realism of the scene. In order to prove the portability between different kind of hardware, the visualization process was also realized in an experimental multiprojection system with three planes. Both multi-projection and monitor implemented test was portrayed as efficient and simple.

Rendering rates were measured with three scenarios, 70 fps for the first, 30 fps for the second and 10 fps for the third. In order to verify scalability of our the proposal, the rendering rates were tested with geographically distributed nodes.

For this, we used one engine for each of the m geographically distributed hosts. In the example, three users at different locations (anywhere in the world) meet in the same virtual world by using stereoscopic glasses (active and pasive), and a Head-Mounted Display, respectively. All users see the same virtual environment from their respective points of view. Each user is presented as a virtual human (avatar) to the other participants. The users can see each other, communicated with each other, and interact with the virtual world.

Some other issues were tested, for example, the collision treatment, that was portrayed as adequate, too. An illustration of the experimental CAVE and monitor tests can be observed in the figure 4.



(a) Cave Structure (b) Different hosts

Fig. 4. Different test geometries.

5 Conclusions

The word “simulation” comes up more and more in the field of industrial/forensic investigation and reconstruction. This tool allows to detect manufacturing layout problems; to determine and validate assembly sequences and ergonomics model aspects; and to make possible critical analysis to show incorrect assessments.

Although the visualization of 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 presented a computing platform to support collaborative multi-VR visualization of unpredicted control situations.

It is proposed to start with dynamic animated scenarios models. After identifying the limitations, restrictions and needs associated with the target problem, a group of procedures that enable the multi-visualizations, with immersive features and VR resources, integrating different existing tools, was proposed. The platform was validated in an actual application associated with a car crash simulation. Scenarios related were modeled, simulated and visualized in centralized and in collaborative multi-VR environments. Up to date, the accomplished visualization and interactive system were proved efficient, concerning the scalability, heterogeneity, portability, rendering, multi-VR media issues and cost. The proposed methodology has been thought to be used in real time visualization and applied directly in the manufacturing/forensic process, by people with no need for specialized programming knowledge.

Future efforts will be directed at obtaining solutions for supporting a better interoperability between platform resources.

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

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