Distributed VR-based simulation for manufacturing.

Li Jin
Ilias A. Oraifige
Frank R. Hall
Paul M. Lister

School of Engineering and the Built Environment, University of Wolverhampton

* Li Jin now works within the Harrow School of Computer Science, University of Westminster

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DISTRIBUTED VR-BASED SIMULATION FOR MANUFACTURING

Li Jin, Ilias A. Oraifige, Paul M. Lister and Frank R. Hall
School of Engineering and the Built Environment
University of Wolverhampton
Wolverhampton, WV1 1SB, UK

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ABSTRACT

VR-based simulation has been applied to a wide range of industrial applications. The rapid development of networking and Internetworked 3D graphics techniques has already begun to foster the distributed VR-based simulation system. The WWW as the delivery mechanism has made the VR-based simulator widely available and affordable. In this paper, we propose a cost-effective approach to create distributed VR-based simulation systems for manufacturing applications. Using this approach, three VRML manufacturing simulators—machining, process flow, factory layout, are described in detail. The current challenges of a distributed VR-based simulator are also discussed.

1. INTRODUCTION

The variety and complexity of manufacturing activities have enhanced the attractiveness of computer simulation as an analysis and design tool. Computer simulation has always played an essential role during the concept phase of product development since it is intuitively appealing and cost-effective. Virtual Reality (VR) as an innovative technology has been applied in the latest manufacturing simulation area. It has transformed the conventional computer simulation from a 2D screen to a 3D space. It provides an e-manufacturing solution for industrial applications not only in a 3D visual way but also in an interactive way.

In this paper, we briefly review current research on VR-based simulation for manufacturing applications. A manufacturing application can be modelled, simulated, visualised and even interacted with in a VR-based simulator. Most immersive manufacturing simulators are often high cost because of the involvement of high performance graphics accelerators, multiprocessor graphics workstations and some dextrous immersive devices. This paper presents a cost-effective approach to create a distributed VR-based simulation system on the Web by integrating Internetworked 3D graphics techniques (Rhyne 2000) such as VRML with Java. Such a distributed VR-based simulator allows multiple users to remotely access and navigate virtual manufacturing application environments for information sharing and collaborative working.

The following section presents some previous work on VR-based simulation in industry. Section 3 proposes a distributed approach for cost-effective VR-based manufacturing simulation using the World Wide Web (WWW). Section 4 describes three VRML simulators for manufacturing applications: machining, process flow planning, factory layout. Section 5 discusses the current challenges in the distributed VR-based simulation area. Finally section 6 draws brief conclusions.

2. RELATED WORK

VR-based simulation has been applied to a wide range of industrial applications. Flight simulation is a pioneering application that has been used to train pilots for many years in the airline industry. An automotive assembly simulator was used by Ford Alpha Simulation Engineering to evaluate process installation feasibility. NASA's Lyndon B. Johnson Space Center has been developing a VR-based simulator to train astronauts in preparation for the Hubble Space Telescope (HST) repair and maintenance (Loftin 1993). The Virtual Wind Tunnel (Bryson and Levit 1992) was a flow field simulator that allowed the user to explore fluid dynamic phenomena. Meanwhile, VR-based simulation has been involved in major manufacturing applications as well. These applications mainly concern:

- Product design and prototyping (Kraftcheck et al. 1997).
- Facility layout design and visualization (Smith and Heim, 1999).
- Assembly process planning and simulations (Ye and Dech, 1999) (Gupta et al. 1997).
- Operations training (Wilson et al. 1998).
- Remote operation of equipment (teleoperation) (Blackmon and Stark, 1996).

The above manufacturing applications have demonstrated the clear potential of VR-based simulation. The involvement of a complex database and some dextrous immersive devices (Head Mounted Displays (HMDs), datagloves, force/touch feedback equipment etc.) makes these simulation systems too expensive to be popular. In addition, not every application needs the full bandwidth of immersion. The rapid development of the

Internet and the Web has already begun to foster distributed VR-based simulation systems. The WWW as the delivery mechanism will make VR-based simulation widely available and affordable.

3. THE DISTRIBUTED APPROACH

A cost-effective approach has been proposed to create distributed VR-based manufacturing simulation systems in order to support remote sharing and collaborative working. Figure 1 shows the structure of a distributed VR-based manufacturing simulation system based on this approach.

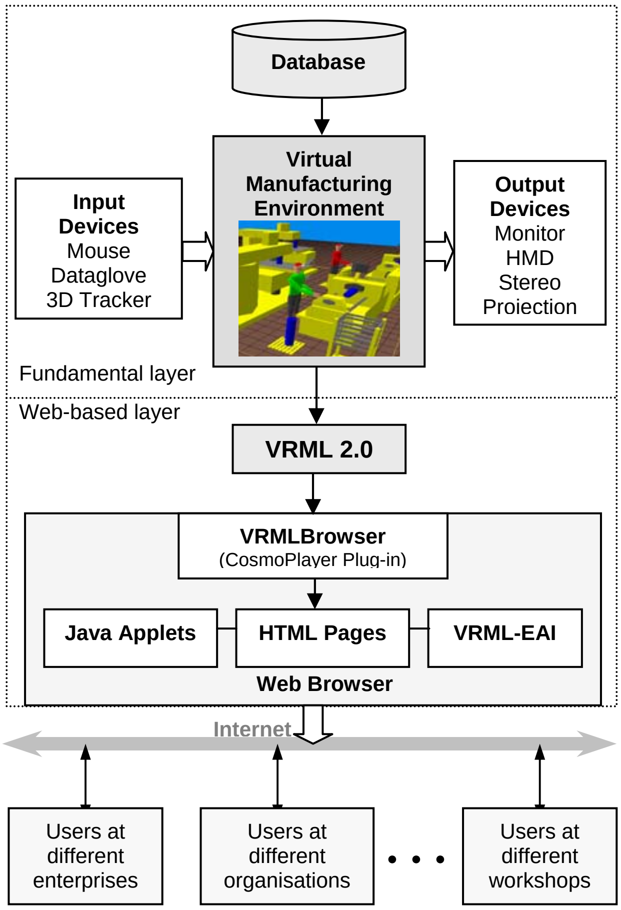

Figure 1 The structure of a distributed VR-based manufacturing simulation system

The system consists of a fundamental layer and a Web-based layer for the Internet access. The fundamental layer is a typical immersive VR system. It supports not only the common monitors but also stereoscopic large-screen projections. It allows engineers to immerse in a virtual manufacturing environment by using a mouse, keyboard and dataglove. The Web-based layer relies on the Internet as the primary medium to create a sharing environment for its distribution. Using standard Web browsers as an execution engine for the simulation system, it enables multiple users such as engineers, machinists and trainees to remotely access, navigate and interact with manufacturing applications represented in 3D virtual worlds at different global sites via the Internet.

The Virtual Reality Modeling Language (VRML) as an International Standard (ISO/IEC 14772) (Carey and Bell, 1997) provides a tool for the description of interactive 3D scenes delivered across the Internet. In our system, VRML has been used as the visualisation integration technology to present manufacturing simulation on the Web. The 3D scenes of a manufacturing application are transformed from the fundamental layer to the Web-based layer by converting the file format of 3D models into VRML 2.0. The Cosmo Player, a VRML world browser, can be embedded into the normal Web browser such as Microsoft Internet Explorer (IE) or Netscape.

The distributed system provides a Web-based graphical user interface (GUI) which is made up of VRML browser, Java applet and EAI. The External Authoring Interface (EAI Working Group 2000) has the mechanism to communicate between Java applet and a VRML scene graph. Thus, the HTML page of the system contains a Java applet running along side the VRML worlds. As an input tool, the Java applet can execute the EAI to update a VRML scene and communicate between the client and server. In this way, the interface allows users to interact and communicate with a manufacturing application provided by this system.

The distributed VR-based simulation system integrates two different disciplines: virtual reality and networking. Generally, such a system should have the following characteristics.

- Distributed. It enables the sharing of a large virtual manufacturing database on the server among multiple users via the WWW.
- Platform-independence. It runs on a wide variety of computing platforms through the Web browser.
- Affordable. No licensed software and additional system maintenance are required for users.
- Scalability. It enables the handling of large numbers of users.
- Extensibility. Hyperlinks to other engineering information systems may be incorporated.
- Collaboration. It supports multiple user access.

4. VRML SIMULATORS FOR MANUFACTURING APPLICATIONS

Three VRML manufacturing simulators have been prototyped according to the above approach. They respectively concern three manufacturing applications: machining, process planning and factory layout.

4.1 Machining

The simulator is prototyped to visualize and analyze the functionality of a machine. It emulates components, tools, controllers and workpiece along with the machining process in a 3D visual way. It enables users preview and explore a new or valuable machine in virtual environments before its purchase. Using the simulator, Engineers and machinists can be trained on the processes of a machine set-up, tool change and production programs.

The simulator focuses on the representation of 3D dynamics machines in real time. The different modelling methods were integrated for this purpose. At first, since Delmia's Virtual NC, a commercial virtual manufacturing software package, provides libraries of 3D virtual machines, it is the choice for anyone wanting a specific virtual machines library. In order to reuse directly the machine models in a virtual world generated by VRML, the model files from Virtual NC should be exported as IGES format. Then, they are converted into VRML 2.0 by a 3D data translation tool. Most common machine models like mills and lathes are achieved in this method. Some samples of VRML machine model are shown in Figure 2. On the other hand, a hybrid method (Jin and Wen 2001) combining the capabilities of VRML geometric modelling with some advantages of commercial modeling packages such as Kinetix' 3D Studio Max can be used to represent some new types of machines such as the latest Computer-Numerical-Control (CNC) machines.

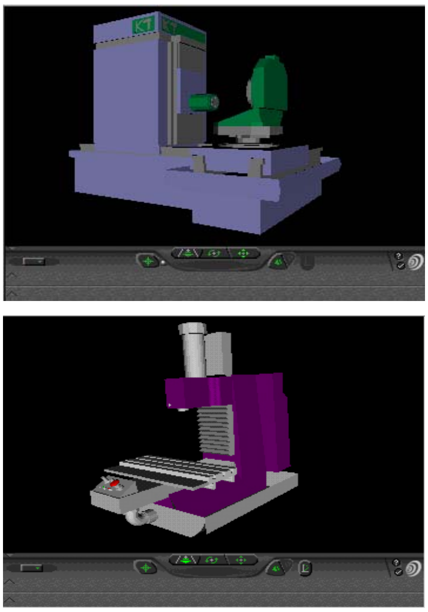

Figure 2 The views of VRML models of machines through the Cosmo Player

4.2 Process planning

The simulator is designed to represent a process flow in a virtual workshop. It aids process planning by process flow simulation and analysis. It is a useful tool for reducing risk and shortening the cycle of product develop before establishing a real process flow.

The simulator emphasises the creation of animations for a manufacturing process. The basic solution is based on the dynamic mechanisms of VRML which combine Interpolator nodes (PositionInterpolator, OrientationInterpolator, CoordinateInterpolator etc.) with Sensor nodes (TimeSensor, TouchSensor, CylinderSensor, SphereSensor) to generate simple animation calculations. For example, the PositionInterpolator node can be used to animate the movement of a workpiece along a conveyor. Arbitrary behaviors can be simulated once script nodes are bound up with the Java and JavaScript languages. In addition, since Delmia's QUEST as a professional manufacturing simulation package can directly emulate real-world process behaviors, its simulation capabilities (Delmia Corp. 1995) can be coupled with VRML worlds via a translator (Wang, 2000) provided by National Institute of Standards and Technology (NIST), USA. Figure 3 shows a simulation of a process flow through Cosmo Player.

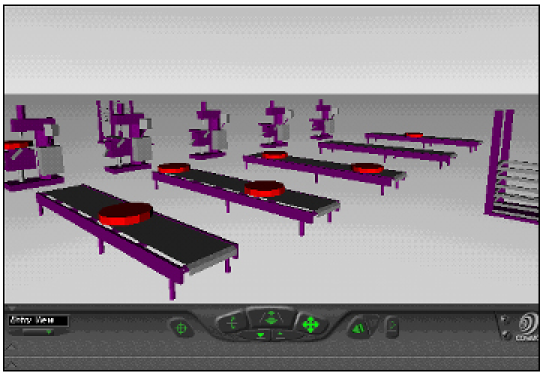

Figure 3 The simulation of a process flow in VRML 2.0

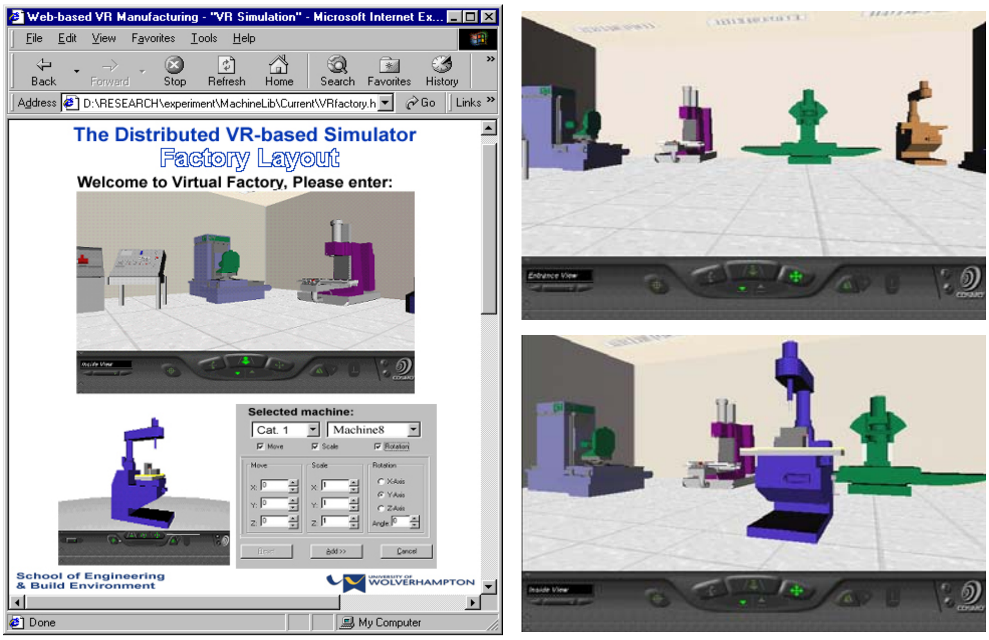

Figure 4 The interface of the simulator for factory layout and some snapshots

4.3 Factory layout

The simulator allows users to design work places and equipment layout before the start of production. An optimal factory layout design according to the rules of ergonomics could maximize the efficiency of workers and achieve the full performance of equipment. The prototype simulator enables users to access a virtual factory and provides the ability to layout the virtual machines. It allows users to select and add new machines into the original world and rearrange them by moving, scaling and rotation. The interface of the simulator along with several snapshots of the virtual factory is shown in Figure 4.

The simulator highlights the reuse of 3D models and the integration of various virtual machines in a VRML world. VRML files exist in a parent-child hierarchical structure. Models are subparts of the world. Such a structure makes it easy to create large worlds or complicated scenarios, which reuse subparts or inherit attributes and behaviors from subparts. As a result, not only a machine model but also its components can easily be reused in various manufacturing applications.

5. CHALLENGES

According to our research, it is believed that a distributed VR-based simulation system should be an entity produced by integrating the following areas.

1. **Graphical applications:** To ensure the implementation of graphics pipeline and maintain real-time display frame rates (at 30 frames/s).
2. **Interactive applications:** To process real-time data input from users. Users should see the virtual environment as if it exists locally, even if it is downloaded from the server across the network.
3. **Distributed systems:** To manage network resources and cope with data loss and synchronization.

There are some challenges when a distributed VR-simulation system is cooperating with a lot of existing application services such as geometric modeling tools, database systems and other transaction systems.

- **Network bandwidth:** It is a key factor in keeping the navigation speed of a distributed VR-based simulator on the Web. The simulator relies on the Internet to share a virtual world and exchange information. Network bandwidth is limited although it has had rapid growth in recent years, especially for the user, who may connect to a simulator via a modem.
- **Real-time display:** Graphical image generation should be guaranteed at 30 frames per second for the real-time display. However, either over-complex 3D graphic scene with huge counts of polygons or very high-resolution texture mapping on the virtual object can lead to display latency. Such delays can result in the loss of the sense of presence.
- **Deployment and browser compatibility:** The distributed VR-based simulation system should ensure that the environment can easily be downloaded and is compatible with different Web

browsers. Its client software should be deployed to multiple users and executed correctly.

At present, some related techniques associated with polygon reduction and image processing have been considered in order to enhance the performance of the above manufacturing simulators.

6. CONCLUSIONS

The cost-effective distributed VR-based simulation system allows engineers and designers to visualise, explore, manipulate and interact with manufacturing applications on the Web. Such manufacturing simulation systems will aid the major activities of manufacturing including manufacturing process concept development and simulation, optimising assembly lines and factory design and layout, and so forth.

With the advent of more effective Internetworked 3D graphics techniques such as next-generation VRML (VRML-NG), MPEG-4, X3D and so on, we will enhance the distributed simulators on a broad base of manufacturing and industrial applications.

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