The Role of Virtual Reality in the Process Industry

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1. Introduction

Until recently, the use of virtual reality (VR) had been limited by systems constraints. Real-time rendering of equipment views places extreme demands on processor time and the invariable need for expensive hardware. As a result, VR solutions were largely ineffective, being unrealistically slow or oversimplified.

However, as VR technology continues to develop, ongoing advances in hardware processing power and software development will allow VR to be used as the interface with computer-based multimedia activities that include training, process design, maintenance and safety.

This paper discusses the range of multimedia VR aids that can be used economically and effectively to support computer-based multimedia activities.

2. Overview

For the purposes of this paper, VR is defined as: “A three-dimensional (3D) environment generated by a computer, with a run-time that closely resembles reality to the person interacting with the environment.”

This environment is further defined as:

- Immersive — where extra computer peripherals (such as goggles and gloves) are used to produce the effect of being inside the computer-generated environment;
- Non-immersive — the environment is displayed in a conventional manner on a display screen and interacts through standard computer inputs (such as a mouse or a joystick).

The key feature that VR brings to computer-aided process engineering is the real-time rendering capability. This has been used to great effect in other areas (such as the gaming, aircraft and medical industries), and is now poised for use within the process industry.

The key to an effective virtual environment system is the close integration of the enabling hardware with software support tools. This process, known as systems integration, demands that operation and implementation — hardware and software — be dealt with together.

However, before considering the type of technology used to implement a VR system for process purposes, it is useful to consider the various forms of the virtual environment.

It is assumed that a VR-based system can only be provided by a head-mounted display. However, a head-mounted display may be the wrong device to use for some applications as it only creates a single-user experience. Therefore, a broader definition of VR must be assumed, one that retains the key attributes of a VR system, for example, the greater sense of presence and interaction the user receives when immersed in a virtual environment.

The technology used to deliver the virtual environment is very important, whereas the technology used to create the virtual environment is critical.

Unfortunately, there is a tendency to think in terms of head-mounted displays when considering VR systems, and this narrow perspective leads to confusion when talking about other types of VR. The solution is to use “VR” as an all-embracing term to cover all forms of VR systems, including stereoscopic auditorium, 3D localisation in conventional projection or a mix of both. Some individuals use the term virtual environments instead of VR adding further confusion. However, it is better to think of a virtual environment as a computer representation of a synthetic world. This means a virtual environment can be defined irrespective of the delivery technology.

However, it is not simply sufficient to produce a lone virtual environment. Their component parts require controlling in such a way that the user believes they are actually immersed in a real environment. This requires a process/machinery simulation tool that interacts with the virtual environment in a tangible action/reaction mode.

Different forms of delivering VR systems are defined by their peripheral technologies. For example, the term “desktop VR” does not relate to the virtual environment, but the delivery technology used. Today, a desktop VR system is generally based on a PC platform, which employs the latest graphic systems to provide optimum performance at a reasonable cost.
3. The Virtual Plant

The 3D content section of the VR environment requires a CAD file as the basic source of the material. This either can be in standard 2D, or advanced formats (such as those created by COMOSFEED™, SMARTPLANT® and AUTOCAD®). These programs generate a 3D CAD® file used to speed up the conversion process required for photo-realistic, real-time graphics. Initially, a basic 3D geometry is created to reflect plant specifications, and then software such as 3dStudioMax® or Maya® is used to process graphics details. This software adds the details and small adjustments needed to turn a flat CAD into a photo-realistic product. Various other tools and applications optimise textures and illumination to further improve the effect.

Unlike conventional, non real-time rendering, a real-time program allows users to move and interact freely within the environment. Special graphic technology permits the environment to be rendered at 60 frames a second, compared to one frame per second in the traditional approach. Specific optimisation techniques are required to achieve 60 frames a second that include the following:

- Level of detail (LOD) geometries, used where the detail is not needed
- UV maps compression for the illumination data that is baked on textures
- Texture tiling to prevent pixel wastage
- BSP/portals generation for large-scale environments

Once the graphics have been created, the next step is to detach the geometries that represent the interactive actors. This is important because it separates dynamic geometries (those that can move and be interacted with) from static geometries (those that cannot).

The final step is to create a collision geometry that resembles the graphics geometry. This allows users to collide with the virtual environment rather than simply passing through the environment.

4. VR Platform and Architecture

The VR interactive system is a server-centric distributed application that centralises scene updates. Therefore, it enables scene rendering to be carried out on many concurrent stations. The server synchronises directly with SimSci-Esscor’s SIM4ME® simulation engine, so the properties of each plant element in the VR scene is constantly updated in time with the process simulation. Other stations have various roles within the simulation and are able to communicate with each other through a network using the standard TCP/IP protocol.

The server application handles communication among the various modules and is responsible for the updated version of all scene parameters. It retains a copy of the scene graph — a hierarchical representation of the 3D scene — that is synchronous with the one present in each satellite application. The server application constantly updates scene graph data, notifying changes via the network protocol to satellite applications.
These satellite applications are in command of rendering the visualised data and providing additional functionality to users. Meanwhile, the main client station reproduces the plant environment and allows users to perform actions on plant elements (for example opening a valve), playing the role of Field-Operator. All actions performed by the virtual Field Operator are tracked and synchronised with the other platform elements, including the process simulator. Outputs can be displayed on various systems, from standard desktop monitors and head-mounted displays to immersive projection systems. Both mono and stereoscopic vision can be used.

The VR system requires a monitoring station that centralises all information on a running simulation. This includes the number and type of connected stations to the 3D model used and specific training exercises being carried out within the simulation. The monitoring station can be integrated with the Instructor Station on traditional OTS systems, giving a single point for managing a full training session. Events and training exercises are triggered by the Instructor Station and transmitted to both the SIM4ME engine and the VR platform.

IPS’ DYNSIM® and FSIM Plus® interface directly with the VR system main simulation modules. They give a fully synchronised integration between the 3D world and the process/control simulation. So any action that the Field Operator carries out in the 3D environment is immediately reflected in DYNSIM. Conversely, any value that is updated by DYNSIM is also updated in the VR platform.

5. Impact of VR on Training

The main advantage that VR brings to both theoretical and conceptual training is that it allows trainees to become much more familiar with the layout and operation of the subject matter. For example, training on a specific piece of equipment not only involves 3D models that can be viewed from any angle, but also allows that equipment to be set in motion. For integrated systems, such as complex processes, VR allows trainees to walk around the 3D model and improve their spatial awareness of the plant.

In addition, when integrated with the detailed DYNSIM simulation environment, VR techniques can be used to enhance the representation of process unit behaviour. There are three main ways for this integration to be represented:

- A navigational front-end representation of continuous rather than discrete state for multi-degree of freedom objects. This supplies visual feedback only, with no equipment interaction
- As above but with equipment interaction
- Complete environment emulation (a synthetic world) by a link between process simulation models and physical-spatial models for all training objectives

Note that giving users a fully interactive view can, in some cases, detract from the objectives being taught, as it can be a much more complex system to understand.
The main elements of a training session are:

1. Setting objectives;
2. Outlining contents;
3. Choice of methodology;
4. Assessment.

The VR platform should guide the user through the development of all the following elements:

1. Setting ‘training objectives’ highlights the different options available:
   - Technical training focussed on transferring technical knowledge
   - Operational training focussed on skills and procedures
   - Safety training focussed on possible hazards
   - Emergency response; how to react to a critical situation
   - Interpersonal skills training (crew training): communication, collaborative decision-making and teamwork

These are all supported by the VR platform. Some training modules may be solely devoted to process knowledge, for example a session that provides greater process understanding for operators. However, most training sessions should deal with all the elements listed above.

2. The majority of the training sessions will be structured around the learning of specific tasks. The content is normally structured in the form of a detailed account of tasks.

3. The VR platform facilitates good teaching practice by allowing trainers to individually match up trainees with the training mode most suitable for them. Therefore, some trainers might introduce tasks slowly in a progressive learning curve, while others might prefer that trainees meet the full task in all its complexity (step-by-step guidance/task guided mode).

4. VR training allows skills transfer rather than simply knowledge transfer. Importantly, it also allows these skills to be tested. So assessing trainee performance becomes a simpler task. Note that the platform also includes alternative modes to score results from training sessions.

6. VR Models in Process Design

Fig. 4 shows an example of iterative and concurrent process design based on the use of VR models. The client/EPC is responsible for the overall design process while the design teams within construction, mechanical, control system, etc., are responsible for the design of the plant subsystems, (such as process equipment, building structure and installations). All design teams are also responsible for providing correct and updated input data to the “VR database”. The VR provider, working for the client, manages all the VR data and makes updated and corrected VR models accessible for everyone involved in the design process.

![Diagram](image-url)  
**FIG. 4:** An iterative design process with specified VR models in a concurrent and multi-disciplinary design situation.
The VR models from 1 to n in Fig. 4 provide the design teams with structured and easy-to-understand design information. This is done in such a way that is not possible using a traditional design approach based on 2D CAD drawings. By navigating in the models, stakeholders can analyse the design from both a general and a more detailed perspective. Moreover, with VR models, it is easier to explain and discuss different design solutions with a larger group of stakeholders, particularly where they have different ways of interpreting 2D design drawings. This ability to collect views from different perspectives gives a better and more productive overall design approach. It also makes it much simpler to discover and correct collisions and design errors earlier in the design phase.

Fig. 5 shows how a VR model identified a bad design solution, in this case process water outlets hindering access. Finding a solution to this type of error after the event is often highly costly. Such an error also affects production by generating delays in the re-scheduling and re-planning of some activities.

During a trial on the use of VR models, users commented that a major benefit of the technology is that it gives a far greater appreciation of other skilled areas involved in the overall project. It also saves time. Said one design manager, “I was sceptical at first. Then I realised that by studying one VR model I could save a lot of time and be more focussed on important issues rather than searching through piles of drawings.”

Increasing time-pressure on projects, partnerships and/or MAC roles is likely to be the stimulus that enhances collaboration between stakeholders. This could lead to a concurrent design approach in which VR models are used to coordinate and communicate the design to the client. In addition, as well as making it easier for them to make crucial decisions, VR models can also involve the client in everyday design work. Being able to quickly sort the relevant information and present it in an easy and comprehensible way enables the client to collect opinions from a wider audience, such as the operations and maintenance staff, and to improve the organisation’s decision-making procedures.

7. VR in Maintenance Tasks

To understand the training aids required for maintenance training, the first sensible, logical step is to look at the task that the trainee is expected to perform after completing the course. In process operations, for example, the organisation of that task is heavily dependent on the industry sector, the range of equipment to be maintained and specific company culture.

Irrespective of the subject matter, however, in general a maintenance task can be broken down into the following subtasks:

- Replication - being able to reproduce the reported fault.
- Identification - being able to accurately diagnose the source of the fault.
- Rectification - correcting the fault by taking action appropriate to the policies of the maintenance establishment.
- Confirmation - checking to see that the identified fault has been cleared. Each of the four stages described above requires a mixture of generic and specific physical and mental skills.
When using VR facilities, the usual approach is to train users to have a deep understanding of both the maintenance task itself and the science behind the involved equipment. This means that the structure of a typical training course includes training objectives that can be taken from a broader number of training categories:

1. Initial Theoretical Training
2. Instructor Led Training
3. Systems Appreciation
4. Fault Diagnostics Training
5. Recognition Training
6. Equipment Familiarisation
7. Scenarios Simulation
8. Visual Appreciation
9. Hand/Eye Coordination
10. Spatial Appreciation

For example, in the analysis of an overall plant working environment, a specially designed avatar of large size could mimic the behaviour of operational and maintenance staff. This is primarily a system analysis (3, 8, and 10) where working spaces, escape routes, risky areas and transportation routes within the plant are investigated from a logistics viewpoint. The result of such analysis allows maintenance procedures to be optimised and highlights if there is a need to ask a design team for improvements or modifications.

A second example (see fig. 6) also refers to spatial appreciation (10), but this time to improve equipment familiarisation (6) and hand/eye coordination (9). The operation of a highly automated industrial process depends largely on the maintainability of its process equipment. Because of the huge economic impact that a failure could have, preventing such events has a very high priority. Therefore, to make sure that maintenance can be properly conducted and performed on time, maintenance personnel can participate in training using avatars or in “first person” through VR models of the process machinery and layout. Therefore, maintenance issues involving diagnostics, timing and procedures can be highlighted and consequently optimised.

FIG. 6: A screenshot showing the use of avatars for investigating the maintainability of the process machinery in the plant.
8. VR in Safety

Using VR, field operators feel completely immersed and perceive the virtual environment as if it was the real plant. By simply putting on their goggles, they are able to see stereoscopically the spatial depth of the surroundings, walk-through the virtual plant and “feel” it. 3D spatial sound contributes to this natural feel, as does the ability to perform tasks using different hand-held devices. Once immersed in a virtual environment where everything resembles reality, all normal and abnormal situations can be experimented on and tested by operators. Any action either in the field or in the control room is simulated rigorously in terms of process behaviour with a clear action/reaction perception. In practice, VR allows operators to test every abnormal situation that can be thought of, alongside little-understood atypical plant behaviours. Both expected and predictable malfunctions can be tested in their entirety, up to and including the disaster that might result. After all, learning from a virtual disaster can help avoid the real thing.

The strength of this approach is two-fold: safety can be tested and experimented upon as a training tool; and risk-assessors are better able to identify hazardous scenarios. Together, they improve the ability of operators to make the right decisions at the right times. In other words, VR makes training, risk assessment and safety management more effective and realistic than ever before.

FIG. 7: A virtual fire.

9. Conclusions

VR provides a 3D computer-generated representation of a real or imaginary world in which the user experiences real-time interactions and the feeling of actually being present.

VR technology is well developed and cost-effective, even for smaller organisations or companies who might be considering its use. The flexibility of VR-based training systems means that they are simple to configure, use and will form an increasingly important element of new training systems.

The ability to simulate complex processes by virtual actions means that trainees experience an environment that changes over time. At the same time, using computer models of real equipment is risk free and allows endless experimentation without the need to take real equipment off-line and risk production. This allows users to learn within computer-generated environments and gives them the opportunity to make mistakes and suffer the consequences without putting themselves at risk.

Overall, VR improves design procedures and is a far superior training tool to more traditional approaches. As a result, it saves both staff time and money.
10. EYESIM for VR

To meet your virtual reality operator training needs, Invensys offers EYESIM. EYESIM is a comprehensive solution linking Control Room Operators to Field Operators and Maintenance Operators by means of a High-Fidelity Process Simulation and Virtual Walkthrough Plant Environment. EYESIM provides complete Plant Crew Training to improve skills that are safety-critical by enabling operators to perform tasks in a simulated environment, allowing them to react quickly and correctly, facilitating reactions in high stress conditions, and instilling standards for team training and communications.

The EYESIM solution is comprised of a modeling engine, powered by SimSci-Esscor’s DYNSIM; services through the SIM4ME bridge, and is coupled with a high performing Virtual Reality Engine and a high quality 3D Modeling/Scanning toolset.