Immersive Virtual Reality Plant
A Comprehensive Plant-Crew Training Solution Improves Process Reliability and Safety

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1. Abstract

Capital-intensive industries face the challenge of replacing an aging workforce with a computer-savvy, gaming generation over the next five years.

Industries such as oil and gas, refining and power companies must institutionalize their workforce knowledge in efficient and effective ways. Leveraging virtual reality (VR) models to improve time-to-competency in critical areas such as safety and environment protection systems, knowledge and performance training, and reliability provides a vehicle to rapidly train this new workforce in ways that align with their interests and skills.

Today, with continuing advances in hardware and software techniques, VR is viewed as the best aid to improving multimedia training, process design, maintenance and safety, which are currently based around conventional 2-dimensional (2-D) equipment views.

The real-time rendering of equipment views places demands on processor time, with the use of high-fidelity simulators becoming the standard in process understanding and training. For many past VR commercial projects, the results were unrealistically slow or over-simplified to the detriment of the solution effectiveness. Today, as technology evolves, these will no longer be an issue with the new process simulation era.

Being innovative is one of the key success strategies of any technology company. Invensys recently unveiled Immersive Virtual Reality Plant (IVRP), a next-generation three-dimensional interactive human machine interface that has the potential for fundamentally changing the way process engineers and operators interact with their plant.

Invensys’ IVRP provides a wide-range of multimedia aids that economically and effectively support design, training, maintenance and safety in the process industry, which is accomplished by linking the power of Invensys’ dynamic simulation (DYNSIM®) to virtual reality (VR) applications and tools.

2. A Revolutionary New Training Medium

Virtual reality is a rapidly growing technology that utilizes the increased power of computers to simulate real or imaginary environments and situations with a high degree of realism and interactivity. It is an emerging technology with potential applications in areas such as product design and modeling; process simulation; planning, testing and verification; real-time shop-floor controls; and training and maintenance. One speculation on the development of virtual reality in the manufacturing industry is a computing architecture that creates virtual production environments within concurrent engineering contexts, achieving zero defect and non-risk production. In fact, virtual reality has already been applied to a wide range of problems associated with manufacturing, industrial maintenance, post-production training and customer services in areas such as visualization of complex data; robot control and remote operation of equipment; communication, training and planning; and virtual prototyping and design. The success of those applications has relied heavily on a realistic virtual environment.

Currently, VR technology is used for training applications in a variety of process industries, and offers the potential to expose personnel to simulated hazardous situations in a safe, highly visual and interactive way. Customized simulations of chemical plants layouts, dynamic process operations and comprehensive virtual environments can be set up and allow users to move within the virtual plants, making operational decisions and investigating processes at a glance. The consequences of correct and incorrect decisions are sent immediately back to the trainees, giving them the opportunity to directly learn from their mistakes.

Users can interact with the virtual worlds using a variety of hardware devices such as joysticks and data gloves. Special optical and audio devices (such as head-mounted displays, three-dimensional graphics and surround sound) allow users an enhanced impression of being in the virtual world.
The overall aim of Invensys’ IVRP is the development of novel training techniques that improve the operation efficiency and skills of chemical plant personnel. This includes the development of a large range of training scenarios for application in the chemical process industry. Using IVRP will increase process understanding, readiness, safety awareness and knowledge of safety procedures, improving production and reducing the plant accident rate.

The large spectrum of objectives for Invensys’ IVRP solution is classified as follows:

- General suitability and potential of virtual reality technology for training applications in the process industry
- Development of a large range of virtual chemical plants environments in which to train operators for a range of scenarios
- Identifying key components and characteristics of the chemical processes and exploring new visuals — intuitive learning technique to be implemented in a virtual world for adequate realism and training acceptance
- Following the new human factor engineering (HFE) trend by broadening the individualized focus on training to cover communication and teamwork

3. IVRP Platform & Architecture

Invensys’ IVRP interactive system is a server-centric distributed application that centralizes the scene update and enables scene rendering on many concurrent stations. It has a central component — the server — that synchronizes directly with the Invensys’ SIM4ME® simulation engine so the properties of each plant element in the VR scene are updated with the process simulation. The VR system has additional stations for various roles in the simulation. All these elements communicate via network, relying on standard TCP/IP protocol.

The server application is in charge of handling the communication among the various modules and keeping an updated version of all scene parameters. It maintains a copy of the scene graph (a hierarchical representation of the 3D scene) that is synchronous with the one present in each satellite application, constantly updates the scene graph data and notifies the changes through network protocol to the satellite applications.

The satellite applications are in charge of rendering the visualized data and providing users additional functionality. The main client station can play the role of the field operator by reproducing the plant environment and allowing a user to perform actions on plant elements (such as opening a valve). All the actions that the virtual field operator performs are tracked and synchronized with the various platform elements, including the process simulator. The output can be displayed on different systems, ranging from standard desktop monitors, to head-mounted displays to immersive projection systems; it can use both mono- and stereoscopic vision.
The main simulation modules that Invensys' IVRP interfaces with are DYNSIM — the powerful high-fidelity process simulator — and FSIM Plus™ — the I/A Series® control system emulation. Invensys' IVRP is also compatible with a variety of process simulators and control systems emulation.

There is a fully-synchronized integration between the 3D world and the process/control simulation. Any action that the field operator carries out in the 3D environment is immediately reflected in DYNSIM and, conversely, any value that is updated by DYNSIM is updated in the VR platform.

Invensys' IVRP requires a monitoring station, which centralizes all the information regarding the running simulation, from the number and type of connected stations, to the specific exercises that played on the 3D model. This station can be integrated with the instructor station on traditional operator training systems, which allows a single managing point to run the full training session. Events and training exercises can be triggered from the instructor station, transmitted to the control consoles (control room operators) and the VR platform (field operators).

The graphic-based instructor station is based on Invensys’ DYNSIM Instructor Station software. The functions described below can be activated using menus and a mouse. The instructor station contains the following control and monitoring features:

1. Run/Freeze  
2. Snapshot  
3. Scenario  
4. Malfunction & Accident Initiation  
5. Instructor Controlled Variables  
6. Monitored Parameters  
7. Trending  
8. Trainee Proficiency Review  
9. Operators tracking in the Virtual Plant  
10. Playback

FIGURE 2: Instructor can track all trainees in the field by a free view camera available as a window on the Instructor Station
4. Augmented Reality

Augmented reality is a combination of virtual and graphic three-dimensional images that are transmitted to a user. Augmented reality differs from virtual reality in overlaying images onto the real (virtual) life, engaging the user in an immersive, interactive and three-dimensional “augmented” environment.

The external environment represents the real (virtual) world and can be linked to additional information systems. For example, in a medical application, it is feasible to overlay a sketch of human organs onto a real (virtual) patient via an optical system. In order to achieve accurate alignment of the real/virtual environments and multimedia data source, it is important to provide the most appropriate link among the display technology, the simulation environment and the information processing systems. All VR scenarios and applications must relate to the external data source either as simulated or as field data. In fact, the value of VR tools and related benefits for training purposes are strictly related to the “action/reaction” feeling of the trainees, as well as the availability of additional info and data, which provide a “supernatural” sense of power and understanding of the process in object.

By superimposing virtual images, videos or text onto real (virtual) life, an experience can be heightened or even modified.

Figure 3 shows an example of a trend diagram, which can be activated/deactivated by the user with a simple touch on the hand device at anytime during the plant walkthrough or a task procedure. Variables and trends can be selected/customized by type (such as temperature, pressure and flow) and equipment exactly displayed in the control rooms. The data source will be identical, simulation engine or real-time database. Alternatively, figure 4 reports a different type of augmented reality, where equipment units become transparent and the information related is shown as a video animation of the process behavior.
5. Emergency, Risk and Safety

There have been a number of recent and well-publicized accidents in which human error has played a prominent role. For example, in Texas City, 1969, the operators opened an escape valve in the overhead product line of a butadiene plant, which was placed on total reflux while other parts were being serviced. As a result, an unstable compound, vinyl acetylene, concentrated in the bottom of the column. Eventually two tons of liquid vinyl acetylene detonated, scattering large pieces of the column up to a half mile, while the fire burned for 60 hours. In order to understand the contribution of human behaviour to the risk of accidents it is essential to examine the errors people make and what leads to such errors. The reduction of human error probability can lead to a reduction in the probability of accidents in process industries. A useful classification framework identifies the human errors as slips/lapses, mistakes or violations. Slips or lapses typically occur through lack of attention or from stressful situations with the result that individuals fail to achieve what they intended. Slip or lapse human errors include forgetting to turn off power, becoming inattentive to important safety checks or forgetting important steps in safety procedures, which may cause equipment damage and loss of lives.

To reduce these errors in operating procedures, effective training methods must be developed. In the past, the objective of operator training was to prevent direct damage, and the loss of lives and property from accidents. Now it includes the wider meaning of developing human resources and increasing the productivity, safety and efficiency of industries. Operator education is now more important than ever before.

Training has always been considered an important factor in staying competitive in a global economy. Operators must remain up to date with the latest methods and technology. Training should involve an introduction to basic hazards and plant safety procedures incorporating fire alarm systems and detailed work safety processes. Therefore, there is a need to create hazardous simulated conditions to provide a real-world (virtual) situation for training without causing harm to the trainee and the environment.

Mistakes can result from incorrect decisions, poor communications and infrequently practiced operations. Typical mistakes include failure to appreciate the dangers of equipment and materials used, misunderstanding of operational procedures and emergency situations or the failure to realize the implications of a process plant. Individual and/or team training is the most effective way to reduce these mistakes. Invensys’ IVRP can help trainees (as individuals or as a team) learn from their mistakes without causing damage to equipment or themselves.

Invensys’ IVRP allows users to navigate in any direction within a computer-generated environment, creating crisis conditions, deciding what actions to take and to immediately see the impact of those actions. IVRP also allows trainees to walk throughout the plant, observe all the equipment that constitutes the process, have the possibility of starting, running and shutting down equipment and responding to error conditions.
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In theory, every abnormal situations an operator can imagine but never test in reality can now be tested, helping the operator understand atypical plant behaviours. Expected and predictable malfunctions can be tested and forced until the accidental sequence results in a disaster. Learning from a virtual disaster can help avoid a real disaster. The main goal is that safety can now be tested and experimented for training and help risk assessors better identify hazardous scenarios. Most importantly, Invensys’ IVRP will aid operators in making the right decisions in time. In other words, Invensys’ IVRP helps make training, risk assessment and safety management more effective and realistic.

Improvement in safety performance has often meant reducing the number of accidents and the potential risk. The process of risk assessment attempts to minimize or eradicate the probability of an accident. Risk assessment has been used informally throughout history, whenever risk is associated with a decision yet to be made or an action yet to be taken. Because the outcome of a future decision is uncertain, different actions may require different outcomes, with some outcomes being more effective. Therefore, human factors can become critical in risk assessment.

Invensys’ IVRP provides a powerful environment to test human behavior in normal and abnormal process conditions by enabling the operator to move around and virtually “touch the reality.” Once immersed in the virtual environment, where everything resembles real life, all critical situations and related procedure/decision making can be experimented and tested.

6. Maintenance & Reliability

Plant maintenance is a best practice that requires a team-based approach, where operators perform various equipment maintenance activities and maintenance crews work closely in the daily operation of equipment.

To understand requirements for maintenance training, the first sensible and logical step is to review the task the trainee is expected to perform and the outcome of that training. For example, in process operations, the nature of the maintenance task is heavily dependent on the establishment’s industry sector, range of equipments maintained and specific culture.

Irrespective of the subject matter, maintenance tasks generally can be broken down into the following subtasks:

- Replication — reproducing the reported fault;
- Identification — accurately diagnosing the source of the fault;
- Rectification — correcting the fault by taking the appropriate action based on the policies of the maintenance establishment;
- Confirmation — verifying 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.

Using Invensys’ VR facilities, maintenance operators can be trained to have a full understanding of the maintenance task and the science behind the equipment they are dealing with. This means that the structure of a typical training course will include objectives that are taken from a broader number of training categories:

1. Initial Theoretical Training
2. Instructor-Led Training
3. Systems Appreciation
4. Fault Diagnostics Training
5. Rectification Training
6. Equipment Familiarization
7. Scenarios Simulation
8. Visual Appreciation
9. Hand/Eye Coordination
10. Spatial Appreciation
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Inherent in VR models is the ability to understand the geometry, layout and/or battery limits of process units and their supporting utility infrastructures. Using a physical representation of an operator or maintenance personnel (avatar), Invensys’ IVRP can be used to optimize gauging and inspection rounds by imitating the operational and maintenance staff behavior.

This is primarily a spatial system analysis (3, 8 and 10) where working spaces, escape routes, risky areas and transportation routes in the plant could be investigated from a logistical point of view. The resulting analysis could optimize maintenance procedures, or request the maintenance management for improvements or modifications.

A second example (see figure 9) could refer again to a spatial appreciation (10) but with a purpose of equipment familiarization (6) and hand/eye coordination (9). In fact, the operation of a highly automated industrial process is largely dependent on the maintainability of the process equipment.

With the aim of preventing production losses, maintenance during operation has high priority in such facilities due to the economical impact. Therefore, to verify that maintenance is properly conducted and performed on time, maintenance personnel are asked to participate in maintenance training using avatars (see figure 8) or in “first person” (see figure 9) through VR models of the process machinery and layout. Maintenance issues on diagnostic, timing and procedures are highlighted and optimized by interactive links to the virtual equipment, as well as to a computer-integrated maintenance and documentation-management system. Therefore, fault-diagnostic training (4) and rectification training (5) can be based on a comprehensive multimedia tool that transfers knowledge and skills (9):
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- Capturing instrument calibration and lubrication activities within a VR model provides the means to integrate and align operations and maintenance activities.
- Integrating operations, maintenance activities and checklists using VR models can provide the means to establish joint ownership and improve teamwork.

Furthermore, model areas can be color coated to represent areas of the plant that require inspection, as well as establish safety and integrity risk boundaries.

![FIGURE 10: Highlighting a plant section](image)

7. Benefits and Value Proposition

Invensys’ IVRP improves design procedures, saves staff time and money in maintenance and is a superior way to train operations personnel:

- Provision of more realistic training environments for trainees
- Provision of opportunity for practice in training sessions
- React quickly and correctly in medium/high-stress situations
- Improving skills for rarely performed, but safety-critical tasks (such as emergency shutdown)
- Optimized transfer of skills from training environment to the work environment
- Reliable and valid evaluation of operational procedures and performance
- Team training: control room, field, shift, operational & safety managers (Communications)

Typical return on investment on an IVRP is more than 50 percent. The technology’s main economic benefits fall within the following main categories:

- On-the-Job Training: saving 30 to 40 percent on time/costs for new large personnel requirements, familiarization in case of mobility from plant to plant and scheduled replacement of the aging workforce
- Start-up Efficiency: saving 15 to 25 percent time to be “back-on-run” and optimal production for planned or unplanned shutdown and frequently having all plant crew refreshed on all critical procedures
- Maintenance: saving 1 to 3 percent on maintenance budgets by improving maintenance operators training and by using IVRP equipment pre-analysis for predictive maintenance
Trainers and trainees can be located throughout the world and using web facilities, remote workers can work together in the same virtual area, on a chemical plant or a building site, resulting in a reduction in travel costs. Interactive programs with multiple sites networked for group learning and communication could be properly developed.

8. 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.