Virtual Reality Tools
for Emergency Operation Support and Training

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Keywords: emergency operation support, training, virtual reality

Abstract

This paper discusses the current state of the art of virtual reality (VR) technology within the context emergency operation support and training.

Recent widely reported fatal road and railway tunnel accidents (e.g. Mont Blanc, Kaprun) have highlighted the problems that arise when evacuating people to safety in the event of a fire in a confined space with limited exit possibilities. Similar problems arise in the evacuation of aircraft and high-speed trains or subways. In order to improve preparedness plans, it is necessary to develop rescue scenarios to ascertain the fire safety and to train rescue personnel by simulation of fire emergencies.

The integration of VR technology with traditional geographical information systems and tools for managing emergency procedures is particularly interesting from both a decision support and training perspective. A VR interface could either replace a conventional 2D interface or complement it, depending on user requirements.

This paper proposes VR methodologies as the only feasible alternative to full-scale fire tests inside tunnels. In a computer simulation-based virtual environment, all data about infrastructure, safety equipment, ventilation resources, fire and smoke propagation, and vehicle/passengers involvement could be managed by a single database. Fire and smoke simulation tools as well as computerised emergency procedures, acting on the virtual data, could also be integrated in such a system and utilised for training support by the emergency operators.

Introduction

VR technology enables users to interact with three-dimensional data, providing a potentially powerful interface to both static and dynamic information.

Since large amounts of spatial and temporal data can be presented directly to the user, it should be possible to improve overall situation awareness using a well-designed VR user interface to an emergency management system.

Since VR systems take a variety of forms, from desktop to immersive systems, with different strengths and weaknesses, it is important to gain an understanding of how current technology can be appropriately applied within financial and technological constraints.

Virtual Reality Technology

Virtual reality (VR) technology enables users to immerse themselves in an artificial environment simulated by a computer, with the ability to navigate though the environment and interact with objects in it.

Two keywords in the field of virtual reality are *presence* and *immersion*. VR immerses the user in a simulation so that the user has a sense of being present in the virtual environment. The degree of immersion depends primarily on the computer hardware used whereas presence is achieved if the virtual environment causes the user to suspend disbelief and accept the computer-generated experience as real.

A computer system that generates an artificial world that tricks the user into feeling part of it would not be a complete definition of VR because it lacks the vital component of interactivity. VR is a three-dimensional user interface in which the user can perform actions and experience their consequences. It is a multidimensional real-time simulation rather than a linear animation with predefined camera movement. This is what distinguishes VR from recorded, computer generated, images used in films and on television and from real-time computer animation where the user is a passive viewer. Unlike pre-rendered images of a 3D environment, the user of a VR system can usually move around freely in a virtual environment.

The manner in which a user interacts with a virtual environment depends on the hardware and software used. In most cases, an off-the-shelf desktop computer with a 3D graphics acceleration and appropriate software are all that is necessary. This form of VR is often called desktop or fishtank VR [1]. In a desktop VR configuration, a 2D pointing-device such as a mouse is typically used to select and manipulate objects, choose menu option, etc. although 3D input devices

Desktop VR is an effective, relatively cheap, option. The desktop VR experience can be taken a step further by using a projector and a large screen to display the virtual environment so that several users can work together in a meeting room or control centre, with one user controlling the computer. The 2D pointing device can also be replaced by a 3D input-device, which may improve usability.

Some 3D graphics cards and software support stereoscopic display, enabling users to view the virtual environment with an enhanced sense of depth using either a desktop display or a suitable projector. Stereoscopic displays typically require that users wear special glasses. Some users find that stereoscopic viewing enhances their spatial understanding, however such display systems should only be used for brief viewing sessions (e.g. up to half an hour) to avoid simulator sickness [2].

For a greater sense of immersion, multi-screen projection systems or head-mounted displays can be used to place the viewer inside the model. While the hardware required to do this efficiently, with motion tracking and 3D input-devices such as gloves, is relatively costly, immersive VR is particularly useful if a realistic view of a virtual environment is required. The user experiences the environment within the model as opposed to looking into it from the outside. VR systems based on immersive technology are relatively expensive, but can be justified when the benefits outweigh the cost.

In order to create usable virtual reality systems at a reasonable cost and with an appropriate level of performance, the application designer's understanding of the advantages and limitations of combinations of VR hardware and software is crucial [3][4]. While the concept of VR is of an immersive system with an intuitive, transparent, interface, the reality is far more challenging from a user interface design perspective. Input devices are often cumbersome and difficult for novices to use. Limited support for haptic feedback means that some activities where touch and feel are important may be unsuitable or may need to be presented to the user in a novel manner in order to circumvent the limitations of today's equipment [5]. Through good design, current VR technology can be very effective within realistic cost and performance criteria.

Multi-user, networked virtual environments [6] offer a range of possibilities for training and operation support. Multiple users can view, and interact with, a shared virtual environment enabling trainees to practice teamwork exercises and geographically remote specialists to effectively participate in guiding a rescue operation. If such systems are to be used in real operations then it is important that communication lines are reliable so that distributed users can make collective decisions based on correctly synchronised data.

VR for Training and Simulation

Training is currently one of the most popular areas of research in the VR field. A safe virtual environment can be used to simulate a real or planned one that is too dangerous, complex, or expensive to train in. There is potential for increasing safety standards, improving efficiency, and reducing overall training costs. VR-based training is particularly well suited to situations where cognitive and spatial skills are important. In general, current VR technology is much less effective than training in a real environment where touch and feel is a significant factor for learning.

A particular advantage over traditional training technologies, such as books and video, is that the trainee is active and can improve skills and understanding through practice. Informal assessment suggests that the level of concentration and involvement required of the trainee results in greater retention of skills acquired when compared with other forms of off-the-job training.

VR technology is often used to build training simulators. The knowledge encoded in such systems is typically only oriented towards enabling the simulation environment to behave realistically. While these systems usually lack integrated support for computer-guided training, they can be run in parallel with systems such as computerised procedure systems, to enhance training. These systems are usually operated with an experienced human instructor present.

VR training systems can go a step further by integrating intelligent computer-based training functionality with a simulator. In addition to behavioural knowledge, the simulator can have knowledge of correct, or appropriate, responses to situations, so that the system is able to guide the trainee, either to teach a correct procedure or to assist the user in making appropriate corrective action [7]. Such systems can be used with instructors in a classroom situation but can also be used by trainees to practice effectively without a human instructor present.

Teaching safety procedures

With its high-voltage equipment and safety considerations, the power industry has been the focus of several research projects around the world [8][9]. For example, in 1998, Statnett SF[1] funded a project at Halden Virtual Reality Centre (HVRC) at the Institute for Energy Technology (IFE) in Norway, where the goal was to demonstrate the viability of using low-cost desktop VR technology for maintenance training activities in high-risk environments.

Using video footage and technical drawings from the early 1970s, HVRC created a model of an actual facility in Halden, containing 47kV switchgear assembled in cubicles. The circuit breakers are mounted on trolleys to facilitate horizontal isolation. The behaviour of the equipment was encoded in the model with the assistance of Statnett's engineers, resulting in a working simulation of the switchgear system.

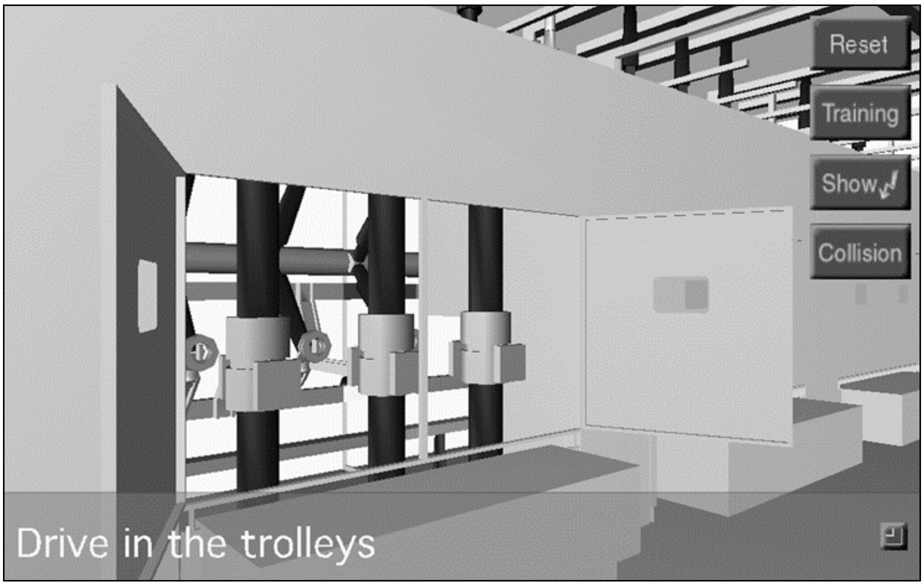

Figure 1. Guided training in a 47kV system.

The correct procedure for safely breaking the circuit, isolating a circuit breaker and cubicle, and then making it again, was coded into the system to enable trainees to be guided through the procedure. The training system provides feedback if a trainee attempts to perform an inappropriate action. Trainees can also switch from the guided training mode to an explorative mode, where they can perform any action and visualise the result. This helps trainees to acquire a better sense of how the circuit works. Figure 1 shows the training system in action.

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[1] Statnett SF is the Norwegian national electricity grid company, owning and operating 9,000 km of high-voltage power transmission lines and sub-sea cables, as well as eighty substations and switching stations.

As an additional aid to understanding what is happening in the model, trainees can choose to visualise which parts of the circuit are live and can examine components from positions that are physically impossible in the real world. Statnett was particularly concerned that engineers should be able to see which parts of the adjacent cubicles are live when a cubicle is isolated, as misunderstandings in the past have resulted in fatal accidents. *Visualising invisible phenomena* (e.g. electricity, heat, or radiation) is relatively easy using 3D software, as long as an appropriate visualisation method can be found so that the information presented is meaningful to the end user.

The user interacts with the model using a standard 2D mouse, which is used to navigate and interact with components. Since the emphasis is on procedures and understanding the electrical system, animation is used to show the operation of components once an action is initiated. Trainees are not expected to move objects around in the 3D space using a 2D mouse as that would make the system much more difficult to use, without significantly enhancing the educational aspects of the model.

The Statnett system is typical of current VR training systems in that it is an application-specific, one-off, solution and, like the majority of the systems described in the literature, it is a proof-of-concept prototype. The Statnett system was developed using ISO VRML97 [10], so it is scalable and portable, but most existing VR training systems, commercial or otherwise, are not standards based, or network-oriented, although web-delivered training is considered attractive by most potential end users. Current systems are typically based on proprietary software running on stand-alone machines (e.g. [8][9][11]).

Lack of portability can be a serious problem if a commercial software supplier goes bankrupt, or withdraws support for a product, and lack of scalability can prevent a virtual environment from being deployed a variety of useful ways. For example, it is clearly attractive to be able to have the option to use the same model on both a desktop PC and a high-end graphics workstation connected to a stereoscopic projection system with as little effort as possible. Cross-platform, scalable, application programmer's interfaces (APIs) such as Performer™ from SGI and Java 3D™ from Sun [12] offer such capabilities, however such APIs have greatest following in the relatively small high-end graphics community, where developers are used to deploying software on a range of computer systems.

Reusable, flexible, computer-based training toolkits that can be used to add advanced training functionality to a VR-based simulator are an attractive possibility. IFE has participated in an EU ESPRIT project called ASSIST [11] where the final product was an intelligent computer-based training toolkit for maintenance applications. The ASSIST toolkit integrates a high-end commercial VR package (DIVISION™ from PTC Inc.) with an equipment emulation system and an intelligent training system. However, the cost and complexity of the various components of the ASSIST package were a disadvantage. The components that were integrated lacked a uniform user interface and offered a confusingly complex array of unnecessary features.

Through the OECD Halden Reactor Project (HRP), work has recently been completed on a proof-of-concept, for a low-cost, Java-based, solution which enables a VRML environment running in a web browser to be monitored and controlled by a Java applet [13]. The applet manages simple safety procedures, enabling the user to be guided and monitored, and enabling instructors to record new procedures by performing them in the model and saving them to a file and then modifying them using a graphical procedure editor. Figure 2 below shows the HRP VR training toolkit in action.

The stability of cutting-edge technology was found to be a problem for general deployment so work in the near future is likely to focus on a looser coupling of computerised procedure systems with VR simulators. Ideally, this would be achieved in such a manner that a real environment can 'simply' be replaced with a virtual one, enabling the same support systems to be used for training that are used for operation.

Figure 2. The HRP VR training toolkit guiding a user through a procedure.

Modelling fire and emergency resources behaviours inside tunnels

One of the strategic projects in the field of emergency management at ENEA is the FIT (Fire in Tunnels) project [14]. One of the initial project objectives will be the design and development of a dynamic accident-training simulator for the long tunnel under construction on the main road between Florence and Bologna. VR technology will be adopted to train emergency rescuers and to enable rapid virtual analysis of accident scenarios. Safety systems inside tunnels must be able to guarantee effective safeguards and have to be particularly suited to:

- quickly locating the fire to facilitate safe evacuation;
- providing total control of the air flow in proximity of the fire;
- effectively managing an emergency in the tunnel, including the evacuation.

The safety systems and structures are commonly divided in terms of *fixed equipment*, *mobile equipment,* and *safety/escape resources.*

The principal *dynamic* element is *fire* whose thermal effects could be mitigated by removal of *heat*, *fuel*, and *oxygen*.

Fixed equipment

The most important of the fixed equipment are the *ventilation systems*. In the ill-omened case of a fire inside a tunnel, the most dangerous elements to be controlled are heat and smoke. Both of these elements can be controlled by adequate ventilation. The two principal ventilation systems are the *longitudinal* and *transversal* systems.

The longitudinal system is founded on the principle of producing longitudinal air movement between the extremities of the tunnel. This type of ventilation is normally applied to one-way tunnels with a single barrel, through a couple of fans, applied at the top of the tunnel.

A tunnel with fans can normally be constructed with *chimneys* in such a manner that, in the event of fire, the length of a smoke-filled zone is limited and the concentration of toxic gas caused by local traffic congestion is decreased.

The transversal system is founded on the phenomenon that warm smoke has a natural tendency to rise towards the top of a tunnel. Extraction gates are installed in the highest zone of the tunnel, while fresh air is introduced by a *forced ventilation system* towards the lower zone of the tunnel.

A transversal ventilation system is normally used in long two-way tunnels, through pipes of ventilation that regulate the influx of fresh air and large exit gates which allow for air extraction. The safety of travellers in transit is assured by the containment of smoke in the higher part of the tunnel and by the presence of fresh air in the lower.

Sprinklers normally represent the first safety guard of buildings and residences but, due to significant differences between tunnels and residences, and the presence of liquid fuels lighter than the water, a great deal of evidence shows that sprinklers not only *result in the ineffective* control of a fuel fire, but can also contribute to increasing the fire and exacerbating the gravity of the event.

Walls of water are an original system that can insulate fire radiation and control smoke. The system is founded on the use of water barriers that isolate a fire, assuring an escape possibility. The system constitutes of reservoirs of water, of 125 metres cubed in volume, placed at distance of 250m from each other and connected to a flexible pipeline furnished with nozzles that enable the formation of walls of water using vertical spray. The water contains an additive that traps smoke decreasing its temperature. Such a system has the advantage of *isolating the smoke* in a section of a tunnel, preventing the spread of a fire outside such a section while giving people an opportunity to escape in the mean time.

Drains have not only the objective of draining away water but in the last few years they have been installed in long tunnels to also drain liquids and inflammable oils that can derive from spilling due to accidents and collisions.

Illumination systems are fundamental for the management of guide and movements inside tunnels.

Mobile equipment

Motor-pumps are mobile vehicles equipped to spray water and foam onto fires and highly irradiated places.

Ambulances are a means of delivering medical first aid, and are especially equipped with oxygen and resuscitation devices.

A special squad of *bikers* is employed for rapid intervention inside a tunnel, to prevent the incorrect management of a crisis situation that could escalate into a dangerous emergency condition.

Safety/escape resources

Emergency *niches, shelters,* and *platforms* are other fixed safety structures that with technical-constructive simplicity preserve intact the tools of safeguard and prevention. Seen in an integral light together with other simple technologies (such as telephones and fire extinguishers), they contribute to decreasing the likelihood of emergency propagation and in the meantime prevent in desiderata complications due to the malfunction of vehicles. Inversion platforms facilitate the evacuation of vehicles in the opposite direction of the accident location.

Escape roads and bypasses are not present in the oldest tunnels, and for some of them the only technical possibility is to analyse alternative solutions. However, in modern tunnels, escape roads have become an important constituent in the view of the overall safety of individuals. In the first long tunnels with transversal ventilation, pedestrian escape roads used the same ducts utilised by fresh air. Escape roads in most modern contexts are founded on the principle of bypasses to safer locations.

Dynamic tunnel simulation for training

Most of the tunnel resources described above have a *dynamic* behaviour and dynamic impact on the external environmental conditions.

Of great importance are the ventilation systems that contribute to reducing the amount of smoke in certain areas so that specific locations can be reached without using special masks and with good visibility if the ventilation is working. This is also the case with walls of water. Drain and illumination systems contribute to improving environmental conditions. Mobile resources can also contribute.

VR training systems for emergencies inside tunnels

Training for emergencies, as opposed to learning safety procedures designed to prevent emergency situations, typically places a greater demand on the visualisation of complex phenomena such as smoke, fire and liquids if the goal is to create a visually realistic simulation. For a VR interface to a decision support system, where the goal is to provide useful information so that the user can confidently make appropriate decisions, an abstract visualisation of such data would probably be most apt as visual realism is more likely to hide than reveal useful information.

Example systems that are commercially available for training for rescue and emergency training include DiabloVR™ and ADMS-VR™ [15][16]. Both of these systems are scenario simulators with modules for generating statistics on trainees' behaviour. An instructor responding to verbal commands from a trainee normally controls these systems.

DiabloVR is a PC-based system that enables accident scenarios to be constructed and simulated. Setting off pre-set triggers based on decisions made controls the course of the scenario. It is primarily designed to teach situation awareness skills and is strong on the simulation of human behaviour.

ADMS (Advanced Disaster Management Simulator) is a VR simulator that runs on SGI workstations and enables trainees to learn in a fully-immersive environment. It was specifically developed for training emergency personnel in handling fire and hazardous materials and provides visually realistic simulation of fire and smoke. It supports scenario generation and unpredictable outcomes in additional to team connectivity for networked training.

The functionality of these systems will be considered as candidates to contribute in the realisation of a FIT VR simulator. However these systems are probably best suited to incidents located in a confined area, such as a plane crash or a road accident, as opposed to accidents in long tunnels or mines that can cover a relatively large geographic region. Within the scope of the FIT simulator, these systems lack integration with computerised procedures for guided, or intelligent, training and advanced decision support, and integration with geographic information systems and databases in order to support operations that cover large area better.

Conclusion

We believe that the use of virtual reality technology is a feasible alternative to full-scale fire tests inside tunnels. We anticipate that systems that integrate virtual reality, visual simulation, databases, expert systems, graphical information systems, and computerised procedures will be utilised for training, also in order to *prevent* more dangerous consequences of accidents, and for operation support by the emergency operators. However such systems are complex and it may take some time until the transition from proof-of-concept prototypes to deployable, dependable, applications is made.

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Dr. Claudio Balducelli is a senior scientist working at ENEA as project manager since 1983 in the field of AI technologies applied to operator decision support systems for emergency industrial accidents. His interests include operator models, knowledge formalisation, planning, computerised procedures, plant diagnosis, case based reasoning, learning and fuzzy algorithms.