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Virtual Reality in the Real World: A Personal Reflection on 12 Years of Human-Centred Endeavour

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Abstract

Over the past decade, the commercial and industrial Virtual Environment (VE) or Virtual Reality (VR) developer community has experienced many problems as a result of the outrageous claims of the early proponents of "immersive" technologies and the dominance of graphics supercomputer companies. Today, the very fact that a commercial, off-the-shelf personal computer, equipped with a low-cost graphics accelerator can out-perform some of its supercomputer "competitors" – at a fraction of the cost it takes to *maintain* those competitors – has rekindled interest in those commercial and industrial organisations who were once potential adopters of VR for competitive advantage. This paper is a personal reflection on some of the industrial trials and tribulations of the past few years of VR/VE developments and a constructive critique on present academic and commercial research and development trends.

Key Words: Virtual Reality, VR, VE, Human-Centred Design, Task Analysis, Ergonomics, Human Factors.

1. Introduction

No more than 4 years ago one could have been forgiven for looking at the Virtual Reality (VR) or Virtual Environments (VE) community, shaking one's head and wondering what had happened to an industry once full of enthusiasm and promise. "A world where your dreams come true…", one was led to believe, delivered by what was described as "…the most important communication medium since television". One was also expected to accept the *de facto* status of head-mounted displays and the notion that "immersion" within computer-generated worlds had become the ultimate in human interface technology for applications as diverse as the training of surgeons or dismounted infantry to the playing of games on domestic PCs or video consoles. Surveys conducted in the UK and the US during this time (eg. CyberEdge 1998, 1999, 2000, 2001; Cydata, 1998, 2000) made reference to – and *still* make reference to – annual markets worth hundreds of millions of dollars (virtual dollars?), with major expenditure on VR technologies being planned and put in place by many large corporations in such markets as petrochemical, defence, aerospace and automotive. However, for companies at the "sharp end" of trading in VR – those providing simulation and system integration services – this level of investment has still yet to be seen, no matter what the size of their organisation.

Having said that, this personal reflection has not been written in order to celebrate the passing of VR – quite the opposite, in fact. It provides a snapshot of some of the experiences, results and problems from the world of VR that have helped to evolve the community out of its naïve "technology-push" state of 4-5 years ago to become an industry capable of responding today to significant market pull and, of greatest importance the needs and requirements of today's and tomorrow's IT users. It is only possible to scratch the surface of today's developments in a paper of this size. However, the interested reader can gain a much greater insight into many of the issues contained herein by obtaining a copy of the forthcoming *Virtual Environments Handbook*, due for publication by Lawrence Erlbaum Associates, Inc. in the Spring of 2002 (Stanney, 2002).

Today, Virtual Reality, or "interactive 3D" (*i3D*), is gaining stronger support than ever before within organisations involved in the design of processes, equipment and systems, and in rapid prototyping, communication and training. However, this process is still taking somewhat longer than most would like. Part of the problem is that there is still a concerning lack of awareness as to what VR is and how accessible it has become, despite major awareness initiatives on the part of a number of influential individuals and bodies, such as the UK's Department of Trade & Industry, whose VR Initiative was carried out between 1996 and 1999. Another problem lies in the fact that the *i3D* community is still suffering from the trivialisation legacy of the early arcade forms of immersive VR. Finally, and this is particularly the case for defence-based organisations, when one tries to categorise VR using the IT or computer-based training guidelines distributed by these organisations, their definitions of VR are often restrictive and erroneous. That is, assuming that VR, as a form of technology-based training, is mentioned at all.

Rather than focus on the technology underpinning VR (as this has been well covered elsewhere), this paper asks the question: what are the key issues surrounding the successful implementation of a VR or *i3D* system, with reference to real commercial applications?

2. Human-Centred Design

Gone (fortunately) are the days when the Virtual Reality salesperson would make such blatant claims as "buy our head-mounted display and all your interface problems will vanish". The quest for the ultimate immersive experience continues unabated, although it is likely that the sensation of total presence within a computer-generated virtual world is still many years, if not a decade or two away. In the meantime it is necessary to suppress the temptation simply to procure the latest and most exciting technologies and concentrate instead on analysing what it is the end user actually requires and the tasks he or she performs. To do this, one must turn to the field of human factors, or ergonomics, for a wealth of experience in task analysis.

Task analysis is a process by which one can formally describe the interactions between a human operator and his/her real *or* virtual working environment (including special-purpose tools or instruments), at a level appropriate to a pre-defined end goal (typically the evaluation of an existing system or the definition of the functional and ergonomic features of a new system). An excellent definition of task analysis was put forward by Bradley of axsWave Software, Inc., based on two IBM documents compiled by Terrio & Vreeland (1980) and Snyder (1991):

> *A task analysis is an ordered sequence of tasks and subtasks, which identifies the performer or user; the action, activities or operations; the environment; the starting state; the goal state; the requirements to complete a task such as hardware, software or information.*

Without a properly executed task analysis, one runs the risk of specifying or designing a VR (or any computer-based training or multimedia) system that fails to record or measure those elements of human skill one was targeting in the first place. One also jeopardises the future integrity of any experimental programme that sets out to validate one's training and assessment concept, not to mention the transfer of training from the virtual to the real.

There is no one "magical" formula for executing a task analysis. The type of analysis employed depends on the human factors specialist involved, whether or not the task exists in reality, the goal of the analysis (eg. are the results required for new system design or training procedures) and any constraints imposed by the analysis environment. It is the author's belief (based on many years of practice) that a task analysis should form an early and central component of any project that involves a major human-centred component. VR projects are no exception.

One important recent development in this respect is the publication of an international standard, ISO 13407 (1999) – *Human-Centred Design Guidelines for Interactive Systems*. This standard specifies 4 general principles of human-centred design and 4 further principles of human-centred design activities, namely:

Principles of Human–Centred Design

(a) Ensure active involvement of users and a clear understanding of user and task requirements (including context of use and how users might work with any future system evolving from the project – if at all),
(b) Allocate functions between users and technology (recognising that today's technology, rather than de-skilling users, can actually extend their capabilities into new applications and skill domains),
(c) Ensure iteration of design solutions (by involving users at as many stages of the design and implementation process as is reasonable practical),
(d) Ensure the design is the result of a multidisciplinary input (again this emphasises the importance of user feedback, but also stresses the need for input from such disciplines as marketing, ergonomics, software engineering, technical authors, etc, etc).

Human–Centred Design Activities

(a) Understand and specify the context of use (including the characteristics of the intended users; the tasks the users perform, or *are* to perform; the environment in which users use, or *are* to use the system; relevant characteristics of the physical environment),
(b) Specify user and organisational requirements (in the context of the present project, this includes aspects of team working, health and safety issues, user reporting structures and responsibilities),
(c) Produce design solutions (with multidisciplinary team and user involvement),
(d) Evaluate designs against requirements (a continuous process throughout the design cycle).

One good example of the success that can be achieved by adopting this human-centred design (HCD) approach is the minimally invasive ("keyhole") surgery simulator MIST (www.mentice.com), the subject of a well-documented range of clinical and applied psychological studies since the late 1990s (McCloy & Stone, 2001; Stone, 2001a). Here, detailed task analyses of surgical procedures led to the development *not* of a high-fidelity simulation of a virtual human body (requiring a highly expensive graphics supercomputer), but of a simplified psychomotor skills trainer, hosted on a commercial off-the-shelf (COTS) PC, capable of generating objective student performance records (Fig. 1).

A related human-centred issue in the field of VR and *i3D* is that of the level of fidelity – an issue that seems to be preoccupying the minds of many potential VR adopters involved with technology-based training at the present time. By adopting an HC approach to simulation design, projects such as MIST demonstrate that one can actually solve the problem of what level of fidelity is necessary to deliver **meaningful training content**, thereby promoting the transfer of training or skills from the virtual environment to the real-world setting.

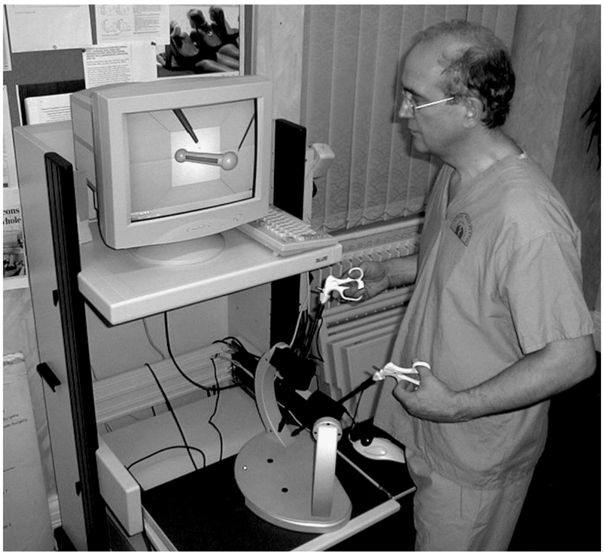

Fig. 1 Minimally Invasive Surgical Trainer, MIST

Another more recent example of the importance of an HCD approach is the TNA scoping project carried out by the author for the NATO Submarine Rescue System (NSRS) Project Definition Study, under subcontract to the Study Prime, W.S. Atkins. Having defined the personnel, equipment and tasks for 3 candidate systems under consideration (manned submersible, remotely operated vehicle or a hybrid system), the HCD methodology led the author to conclude that over 80% of the tasks expected of the NSRS team did **not** warrant *i3D* or any other form of high-tech training.

As the NSRS hardware will probably be available for training throughout a given year (ie. at times when it is not required for deployment on exercise or actual submarine rescue), investment in high-tech training simulators would not, in this case, deliver a cost-effective solution. Where *i3D will* deliver training content of relevance to the end users of NSRS is in the form of a real-time submersible navigation/piloting simulator (Fig. 2), capable of varying such mission-critical, "what-if" parameters as ocean bed turbidity, current strength and direction, submersible propulsion reliability, power failures, surface ship dynamic position-keeping problems, distressed submarine resting angle, artificial lighting sources and so on.

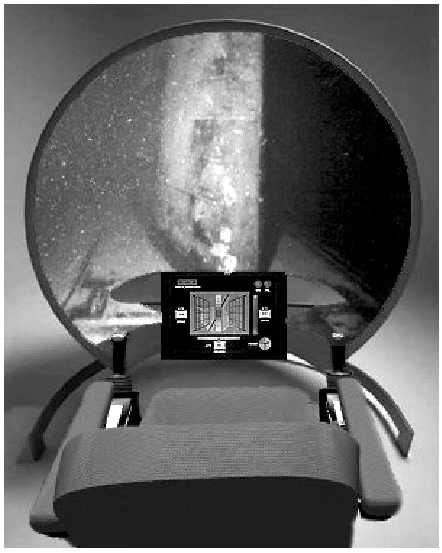

Fig. 2 NSRS System VR Training Concept

3. Appropriate Interface Technology

The author's experience of adopting a human-centred approach to *i3D* applications, coupled with the findings of recent market surveys indicate that, of all the various technologies available for displaying and interacting with virtual environments, the ubiquitous keyboard and mouse are still top of the data input league, accompanied by the standard workstation or desktop PC screen for data display. This is testament to the fact that, despite the impressive nature – the "wow factor" – of Reality Centres, CAVEs, back-projected workbenches, head-mounted displays (HMDs), and so on, the majority of *i3D* applications outside of the academic laboratories **simply do not warrant expenditure on these high-end facilities**.

The fact that the organisations wishing to adopt *i3D* solutions also cannot *afford* such facilities is, of course, also important to recognise! Academic initiatives attempting to attract companies of all sizes to their costly facilities as part of a VR adoption/education package have consistently failed to generate credible results.

Single-screen (wall-size) projection facilities, sometimes using passive stereo (twin polarised projectors) or active stereo (single projector field-sequential LCD glasses) come a reasonable second place to desktop VR. Some of the new high-luminance data projectors are finding favour with those conducting design and project reviews for virtual prototypes on a 1:1 scale with the human observers. HMDs, in conjunction with spatially tracked hand controllers or "wands" (as opposed to instrumented gloves – the "technology of choice" in the late '80s and early '90s) are making a slow comeback, but only in applications where they are used in tandem with other physical components existing in the real world, as will be discussed under "augmented reality" below. One technology that appears to be maturing quite rapidly is haptic (force/touch) feedback, with products such as Sensable Corporation's *PHANToM* feedback device (www.sensable.com) delivering impressive results in areas as diverse as ceramic design, undercarriage maintenance for the A380 and mine clearance training for the French Army.

For example, British companies such as Wedgwood and Royal Doulton, famous international, historical names in the production of quality crockery and figurines, have turned to VR in an attempt to embrace technology within their labour-intensive industries. Ceramics companies and groups, such as the Hothouse in Stoke-On-Trent, are experimenting with new haptics techniques and achieving some quite stunning results (Fig. 3).

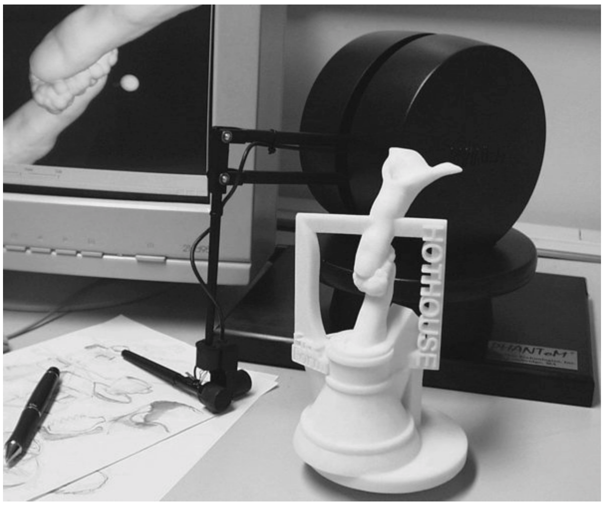

Fig. 3 Virtual and Real Sculptures Created Using the *PHANToM* Haptic Feedback Device

The importance of experiments like these, however, lies not so much in the results but in the people who actually *produce* the results. Talented sculptors – people with incredible manual skills but *no* background in computer technology whatsoever – have, given access to the *PHANToM* and *Freeform* "digital clay" products, started to produce ornate sculptures *within 3-4 days*! Then, using local industrial resources, they have used 3D printing and stereolithography facilities to convert these virtual prototypes into physical examples and high-end VR to display them in virtual showrooms and domestic settings of very high visual fidelity.

Another relevant project in this category is supported under the European Union's Framework V Initiative and is called *IERAPSI*, an Integrated Environment for Rehearsal and Planning of Surgical Interventions. Continuing on the human-centred theme described earlier, early *IERAPSI* work packages related to the analysis of surgical procedures (again based on ISO 13407), specifically focusing on surgical activities underpinning mastoidectomy, cochlear implantation and acoustic neuroma resection (Stone, 2000). The surgical procedures definition and task analyses were conducted in collaboration with the ENT department of Manchester's Royal Infirmary. These exercises resulted in the selection of the *PHANToM* Desktop/1.5A for haptic and vibratory stimuli when simulating the use of pneumatic drill (through cortex and petrous bone) and a second *PHANToM* device for irrigation and suction (Fig. 4).

Fig. 4 The IERAPSI Temporal Bone Training Simulator Workstation

4. VE Content

An HCD approach to simulation design will take account not only of the qualities of the target user population and the tasks expected of them, it will also help to optimise the price-performance envelope of the host computing platform. For example, research conducted for the UK's Flag Officer Submarines (FOSM) between 1997 and 1998 considered a number of techniques for delivering virtual SSN and SSBN submarines to naval ratings undertaking basic Submarine Qualification (Dry) (SMQD) training. FOSM, together with other branches of the RN submarine training organisation were targeted by commercial organisations offering quite different solutions to developing a virtual boat trainer, from photogrammetry-derived CAD to custom-built *i3D* models, and from basic PowerPoint or HTML "walkthrough" presentations to digital panoramas (eg. using Apple's *QuickTime VR*, MGI's *Photovista* and others).

An HCD approach to defining the information actually required by a novice submariner and how it should be delivered (depending on whether the task involved spatial awareness, systems tracing, compartment familiarisation, safety equipment location and operation, etc.) revealed that these content generation techniques could not deliver meaningful training when considered in isolation. What was required was an integrated approach to using simplified *i3D* hull, deck and compartment models, enhanced where necessary by detailed systems representations (high-pressure air, hydraulics, electrics, etc.) extracted from CAD databases (Fig. 5). High visual fidelity can be provided on a selected compartment-by-compartment basis using panoramic techniques, enhanced using individual 3D models of valves, controls and line replaceable units. This solution also guaranteed that the complete SMQ(D) simulation could be hosted on a COTS Windows NT PC as opposed to a dedicated VR computer costing 10 to 15 times the price. These concepts will now be applied to the development of the SMQ(D) element of the new *Astute* Class SSN submarine.

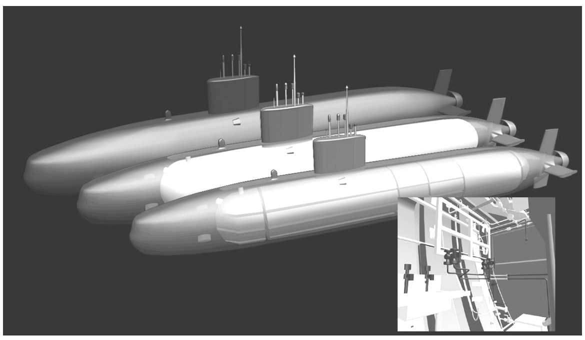

Fig. 5 Spatial Navigation Database for Submarine Qualification Training Derived from CAD

5. Augmented Reality

Although based on anecdotal experience at the moment, there is a body of evidence suggesting that the fidelity and "believability" of *i3D* or VR simulators can be enhanced using a variation of what is known as *Augmented Reality* (AR). Throughout research circles Augmented Reality is used to describe situations where users, typically confronted with very complex *real* scenes (patients undergoing surgical interventions, petrochemical plant interiors, etc.), exploit modified immersive VR technologies – semi-transparent head-mounted displays with integrated miniature cameras, for example – in order to superimpose task-relevant virtual data onto the real scene. In fact, this form of AR is still in its infancy and relies highly on the accurate registration of the position and orientation of the user's head to guarantee a match between the virtual and the real (Stedmon & Stone, 2001).

However, there is another, and more mature variant of AR, where elements of the *real* world are used to enhance the (sometimes limited) fidelity of the virtual world. At its most basic level, this demands that students exposed to pure VR training, as in the case of Virtual Presence's Avionics Training Facility for the *Tornado* Maintenance School at RAF Marham, for instance (Fig. 6), should (for health and safety reasons at the very least) be exposed to a continuum of actual physical components, such as line replaceable units of various sizes and weights (Stone 2001b; Stedmon & Stone, 2001).

The choice of appropriate peripheral interface device also falls within this basic level, with the device chosen supporting some degree of familiarity between the user and his or her "tools of the trade", as was found with the sculptors when using the *PHANToM* haptic feedback system, described earlier.

Fig. 6 RAF F3 *Tornado* VR Avionics Trainer Database

Taking this one step further, however, is there merit in using basic physical mock-ups of actual systems in conjunction with VR? On a simple level, the French Army mine detection system mentioned briefly earlier is based on a COTS haptic feedback system modified to support a standard ground probing stylus. As another example, the mobile excavator company FERMEC uses a cut-down version of a real backhoe digger cab seat, complete with joysticks, to augment the experience of their immersive virtual prototypes during design reviews and introductory training (Fig. 7). Many of the automobile companies use seating bucks in combination with immersive VR to evaluate the ergonomic and aesthetic aspects of proposed car interiors. By realistically constraining the user's posture and providing them with interior surfaces that double as a form of tactile cue or "reach delimiter", the visual VR experience becomes much more convincing than if the user had been provided *only* with a visual VR experience delivered via an HMD.

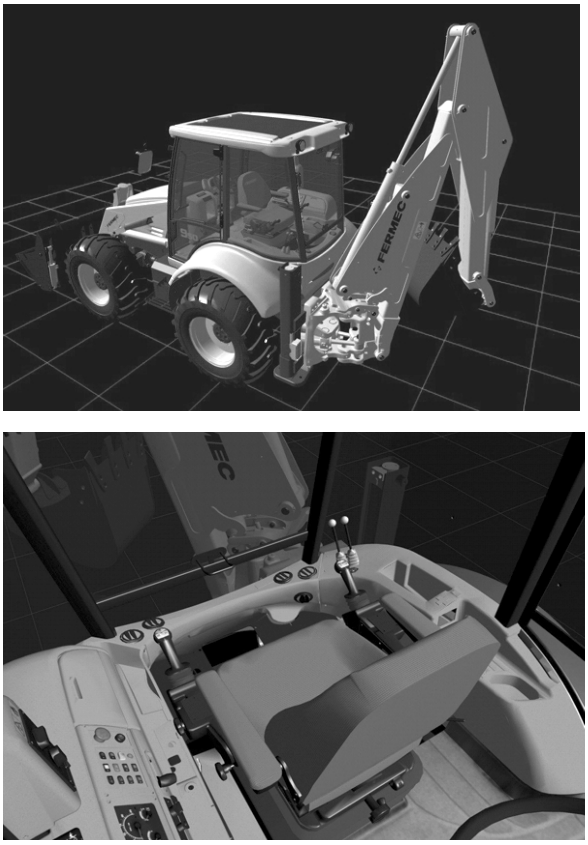

Fig. 7 FERMEC Virtual Back-Hoe Excavation Vehicle and Cabin Interior

In the naval training sector, a good example of real equipment augmenting the synthetic experience is the Close-Range Weapons Simulators commissioned by the RN's Naval Recruitment & Training Agency (NRTA) for HMS Collingwood in the south of England. Here, 20/30mm weapons aimer and director students don head-mounted displays and are presented with a synthetic environment, creating the effect of being located on the port side of a generic Royal Navy vessel. The aimer's task, under conditions of variable sea state, precipitation, fog and time-of-day, is to engage surface and airborne threats under the instructions of a Weapons Director Visual (WDV). The VR headsets used – Kaiser *ProView* XL-50s – do not fully enclose the eye orbits of the students, as would other headsets. Instead, their design affords students some peripheral vision in both azimuth and elevation. As well as the VR environment, students interact with *real* weapons hardware, made available when the original shore-based training facility near Plymouth closed down earlier in 2001. In the case of the 20mm GAM BO weapon, the aimer is normally strapped into the shoulder rests, thereby helping to maintain a fixed relationship between the eyes and gun sight (Fig. 8).

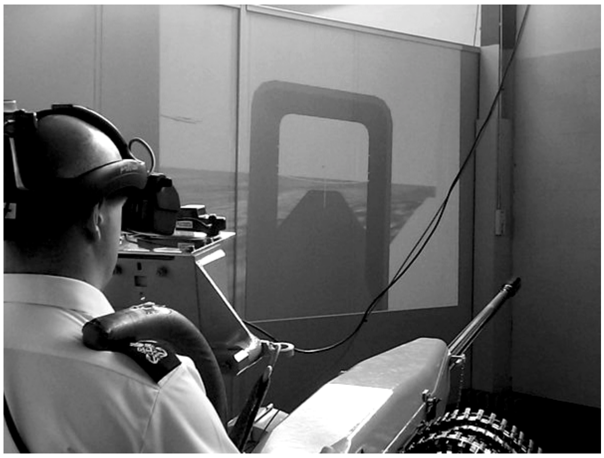

Fig. 8 Royal Navy's Semi-Immersive 20mm Close-Range Weapon Trainer

As the sight is not present on the RN's simulation facility weapon, both the gun and the aimer's head have to be tracked in order to preserve this visual relationship. Also, as aimer looks around, other parts of the virtual ship come into view, including a virtual Weapons Director Visual supervising activities from a raised Gunner Director's Platform (GDP).

In a similar vein, the WDV (also equipped with a headset) can look down from a physical mock-up of the GDP (Fig. 9) and view the virtual aimer strapped into the virtual gun. The Kaiser HMD design enables the aimer to view parts of the real weapon peripherally, including the firing mechanism and gun locks.

This further avoids any problems of disorientation that might be evident with a headset that enveloped the eyes completely. Similarly, in the MSI 30mm gun example, where the aimer actually sits at a small weapon control panel, the VR headset affords visual access to the real panel, as well as displaying it in the virtual reproduction of the weapon. Real visual access is achieved by glancing down (eye movement only), whilst the virtual panel comes into view when the aimer's head rotates downwards.

Fig. 9 WDV With HMD on Platform Above Weapons Aimer

6. Assessment and Evaluation

One of the important features that should be considered by the sponsors of virtual training systems is a requirement for their commissioned software to perform human performance data recording with some degree of early analysis and evaluation. In the case of those simulators designed according to human-centred principles, the definition of key performance parameters and the integration of software modules to collate relevant data for post-session analysis (and **not** just playback for debrief purposes) is reasonably straightforward. The MIST example described earlier is one good example of this concept and has been used by the author's company to develop *FrameSET*, a self-contained modular software architecture that can be adapted to future training systems, both stand-alone and networked, to provide a complete pedagogical service, from simulation parameter set-up to data collection and analysis (over the Internet if required; Fig. 10). Another example can be found in an ROV simulator developed by Imetrix Inc of Cataumet, US. *ROV-Mentor* collects and presents data on performance objectives that were developed from extensive task analyses and studies of expert submersible pilots.

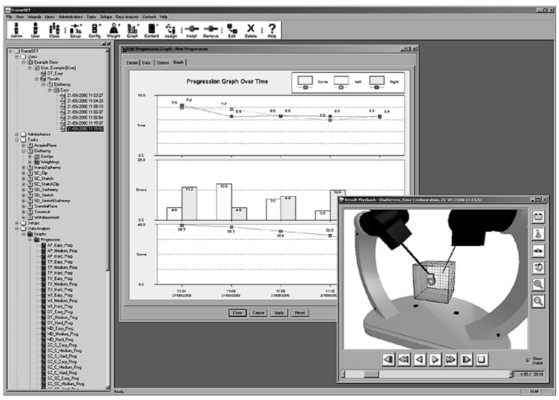

Fig. 10 *FrameSET* Screenshot Example During Replay of Surgical Student's Task Performance

Unfortunately, however, this is an area that warrants much more attention than can be given by commercial VR companies and offers an exciting opportunity to the academic community to research and develop usable, pragmatic tools that enable defence training organisations to evaluate their VR simulators, generating objective measures of situational awareness, transfer of training, information recall, and so on.

It is a regrettable fact that many of the world's so-called academic centres of VR "excellence" have, to date, been preoccupied with possessing and announcing the biggest and best equipped VR facility. This has meant that quality research ideas and programmes, focused on the needs of the wider VR user community, have not been forthcoming. There are a handful of notable exceptions to this rule, but surely it is now time for the industrial and defence communities to demand much closer involvement with – and supervision of – university-based VR teams to make sure that their efforts take full account of what is happening in the real world of *i3D* and simulation.

7. VR Software Standardisation and Reusability

Within various government ministries at the present time (industry, trade, defence, etc.), there is much talk of the importance of centralising digital resources in order to promote standardisation across their particular community in everything from *e-learning*, distributed simulation, 3D computer-generated models and simulation code to Smart Procurement and Continuous Acquisition and Life-Cycle Support (CALS). Focusing on the VR community, one of the major problems faced in trying to accelerate such a standardisation across the defence industry is the fact that, over the past 12 years, there have been so many different approaches to 3D graphical modelling, Computer-Aided Design (CAD) data conversion, VR database management, real-time rendering and distributed simulation. Some historically well-known VR companies have ceased to exist simply because of a change in emphasis by larger suppliers of their core real-time software system.

Returning to the issue of fidelity, it is always interesting to witness the behaviour of domestic computer games software users and how, from a psychological standpoint, they manage to achieve *full immersion* in their endeavours without the use of sophisticated HMDs or video projection facilities such as CAVEs. Today, every computer-owning parent will be able to recall many instances in which an addictive first-person "shoot-'em-up" game has induced "tunnel vision" and focused auditory attention in the young computer specialists of tomorrow! Titles such as *Project IGI*, *Delta Force*, *Operation Flashpoint*, *Soldier of Fortune*, and e-Sim's acclaimed *Steel Beasts* tank simulator spring to mind in this respect – all of which, quite frankly, put some of today's expensive *i3D* simulations to shame in terms of visual quality and combat effects.

But even before these graphically detailed covert operations and mercenary publications burst onto the scene, many will remember *Battlezone* – a wire frame tank game published in 1983 for the Atari, or *The Colony* – a space survival game created in 1988 for the Apple Macintosh by David Smith (also the founder of Virtus Corporation in 1990 and accredited with developing the first VRML Internet tool kit in 1995). Then there was the revolutionary *Wolfenstein* (1992, soon to be relaunched as *Return to Castle Wolfenstein*), *Doom*, *Quake*, *Hexen*, *Heretic*, *Unreal* and *Half Life*… the list goes on.

The graphics may appear crude and simple. But as long as the user's attention is captured and he or she is required to maintain a spatial and temporal awareness of the 3D situation in order to survive within the scenario, and as long as the simulation responds meaningfully in real time, a training simulator can be designed to deliver valid, reliable and believable content to highly motivated students of all ages and skills.

Virtual or synthetic environments delivered using games software must no longer be thought of as a trivial or unprofessional solution to the needs of *i3D* or VR developers. Evidence suggests that computer games actually improve logical thinking, strategic planning, observation skills, problem solving and many other cognitive and psychomotor skills.

Some companies are now even supplying simulators for nuclear control room activities, chemical plant maintenance and offshore platform evacuation training, based on, for example, Epic Games' *Unreal* engine (www.epicgames.com/unrealenginenews.html). Epic's latest *Unreal* engine, codenamed *Warfare*, has been used by researchers in Gifu, Japan and the US to develop a brand new action/strategy game called *Devastation* (due for launch in 2002) and was the underpinning technology for an impressive synthetic data fusion demonstrator based on a dynamic climatic model of Snowshoe Mountain in West Virginia (Thrane Refsland, 2001). The Snowshoe demonstration uses satellite data, environmental sensors and real-time GIS data to render large-scale, virtual environments that foster virtual life and natural behavioural conditions (Fig. 11).

Only now are VR developers following the practices of games developers in exploiting emerging graphics acceleration hardware and adopting, for example, industry-standard, cross-platform applications programming interface (API) standards such as OpenGL. Also, the archiving of synthetic 3D models in robust formats such as VRML (Virtual Reality Modelling Language) finds favour with many VR developers, reducing the size of models built using such packages as 3DS Max to a level compatible with Internet sharing and review.

Fig. 11 Virtual Snowshoe Mountain Dynamic Climate Demonstrator (*courtesy Scot Thrane Refsland*)

The line replaceable units developed for the RAF's Avionics Trainer, mentioned earlier, were all archived in VRML and were therefore capable (subject to classification) of being e-mailed to the prime contractor and end users for visual QA approval using a free down-loadable 3D browser (*Cosmo Player* – Fig. 12 – or *Cortona*). As for operating systems, the jury still seems to be out on the issue of NT or future Windows releases *vs*. the Unix family (including Linux).

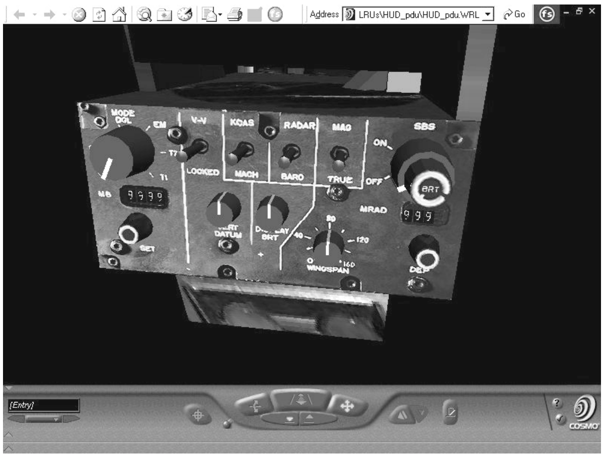

Fig. 12 Part of the RAF F3 *Tornado* Head-Up Display Archived as VRML (.wrl) and Viewed via *Cosmo Player*)

All being said, the evolving *real* commercial interest in VR for training and design is producing a number of software applications which, suitably managed, could bring major benefits and cost reductions to future training contracts by reusing real-time code and 3D models. For example, in the case of developing a VR helicopter search-and-rescue training system (a project started in October of 2001; Fig. 13), the re-use of the virtual ocean, time-of-day and weather simulation modules developed for the Royal Navy's gunnery trainer, described earlier, is saving considerable project time and money.

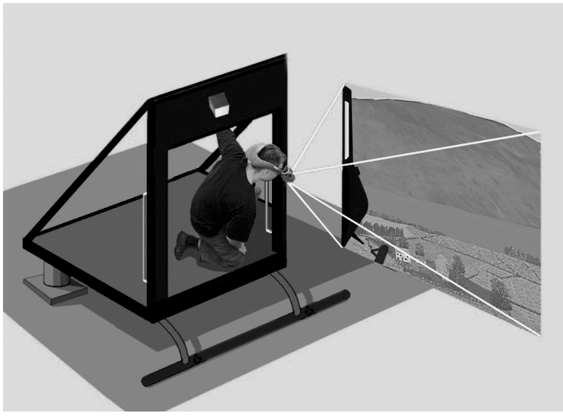

Fig. 13 RAF Voice Marshalling VR Training Concept (Upper Image Shows Actual View from Griffin Helicopter)

Returning to submarine training, it has been recommended that the future developers of virtual environments for the *Astute* class submarine and, if accepted, the new NATO Submarine Rescue System (NSRS) take full advantage of *i3D* efforts being expended in both areas. Then trainee submariners would be able to rehearse emergency evacuation from their virtual *Astute* SSN into a virtual NSRS system, as well as the NSRS pilot gaining experience in mating with that class of vessel. These are just simple examples that scratch the surface of a truly integrated digital service for future industries – from defence to aerospace, from heavy engineering to education.

8. Conclusions

Overall, recent developments in VR or *i3D* have been very encouraging indeed (Stone 2001b). Examples of the potential contribution virtual or synthetic environments occur with increasing regularity in texts inviting companies to pre-qualify for a particular study or development project, even with the impact of falling budgets in certain sectors. Potential industrial or commercial VR users need no longer be shackled by over-priced, high-end/high annual maintenance computer architectures and display peripherals. They can now rest assured that a major proportion of the design or training applications in which they are interested can be delivered using COTS PC hardware with sub-$600 graphics cards. Content development costs are on a par with Computer-Based Training (CBT) offerings and, in the majority of cases, are significantly cheaper, with minimal resources necessary for through-life support – annual maintenance and technology refresh, for instance.

Eight years ago, the author wrote a paper entitled "Virtual Reality Comes of Age". With hindsight, that title was wildly off the mark and optimistic. Today, however, the foundations are in place to help VR "come of age" and, with some reality-focused effort on the part of the academic community, VR is set to deliver quality design, prototyping and training facilities for many decades to come.

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