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Keynote Address 2: Available Virtual Reality Techniques Now and in the Near Future (Unclassified and for distribution to all NATO nations)[1]

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Summary
This paper presents available virtual reality technology as well as technology that is projected to become available to NATO in the near future. Areas discussed are new PC technology (graphics rendering and wearable computers), personal and large-volume displays, large volume tracking, force feedback interfaces, and software toolkits. PCs presently render millions of polygons/sec. Their reduced cost makes possible the distribution of virtual environments at many sites and in many countries. Large-volume displays are more expensive, but allow more natural user interactions. They do require large-volume tracking that is fast and accurate. Haptic interfaces are a recent class of input/output devices that increase simulation realism by adding the sense of touch. This comes at a cost of more computing power and better physical modeling. The modeling and programming needs of virtual reality are met by software toolkits designed for such simulations.

1. Introduction
Virtual reality technology has experienced significant advances in the late nineties, and now has many characteristics that may be exploited by the military. Virtual reality has the potential to significantly reduce training costs and the risk to him. It also has the potential to reduce *team* training costs, allowing multi-national organizations, such as NATO, to have a unified training system, without a unique training location. Virtual reality, as a computerized training environment, allows transparent gathering of data, and the remote access to such data, at a much smaller time interval, and resolution than allowed by manual data collection methods. For all these reasons it is important to inform the military decision-makers of what technology and methods are available today, or what will become available in the near future.
This report is based on the keynote address given by the author at the NATO Workshop that took place in April 2000 in Hague. Then, as now, the time and space available for such a review are limited. When trying to condense all this material, which can easily take a Semester to teach in college, certain things had to be omitted. Thus the present review does not cover networked communication as it applies to shared VR, nor does it cover human factor trials of VR technology. Such topics are covered in companion papers. Emphasis here is on commercial off-the shelf technology, or technology that is close to commercialization. Many deserving research projects are omitted here, as a matter of practicality. The interested reader who wants more information on such research should consult the open literature, such as the *Proceedings of the IEEE Virtual Reality Conference* series (formerly VRAIS), and other such publications.
Section 2 of this report presents significant changes in the computing platforms that are (or may be) used in VR. Section 3 describes the displays that output the graphics scene to the user, whether such displays are personal or large-volume. Large-volume displays, in turn, require large-volume trackers, which are the subject of section 4. Section 5 presents the newer haptic interfaces, which bring more realism to the simulation by allowing the user to touch and feel virtual objects. The modeling libraries needed by modern VR simulations (including haptics) are detailed in section 6. Section 7 concludes this report.

2. The PC Revolution
Probably one of the most important changes that has influenced the VR arena in recent years is the tremendous increase in PC-based graphics rendering speed. The closing gap between inexpensive PC-based graphics and the high-end SGI engines is clearly illustrated by Figure 1.
The measure of performance used for comparison here is the number of polygons rendered by the computer in unit time. When dividing this number by the scene complexity, one obtains the screen refresh rate in frames/second (how many snapshots of the virtual scene the computer can render per unit time). The more complex the scene, the less frames/second, which in turn can result in a disturbing saccadic graphics [Burdea & Coiffet, 1994].

[1] Based on the author's presentation at RTA/HFM Workshop 007, The Hague, Netherlands, 13-15 April.

Paper presented at the RTO HFM Workshop on "What Is Essential for Virtual Reality Systems to Meet Military Human Performance Goals?", held in The Hague, The Netherlands, 13-15 April 2000, and published in RTO MP-058.

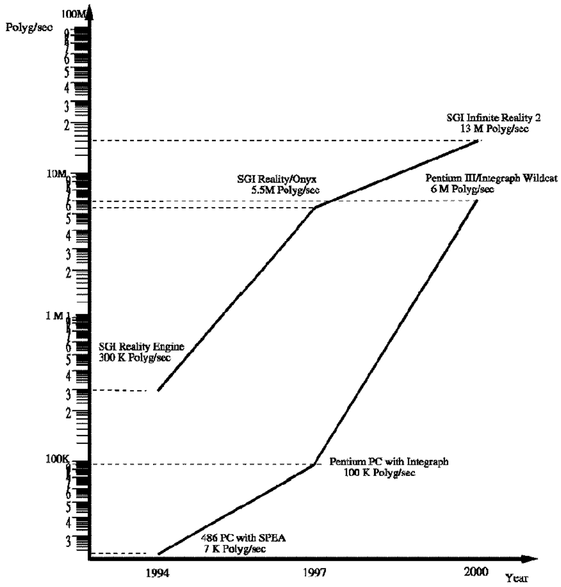


Figure 1: SGI graphics vs. PC-based graphics

In 1994 a 486 processor PC with SPEA FIRE board was capable of 7,000 polygons/sec. A modern Pentium III PC with Wildcat graphics board can do 6,000,000 polygons/sec, and costs only 6,000 dollars or so. During the same time the performance of high-end graphics workstations produced by SGI rose from 300,000 polygons/sec. on a Reality Engine in 1994 to 13,000,000 polygons/sec. today on a multi-pipe Infinite Reality 2 [Real Time Graphics, 2000]. While its performance is twice that of the fastest PC rendering board, its price is two to three hundred thousand dollars, which makes it affordable to only a few! By significantly improving performance, while actually reducing costs in the late nineties, the PC industry made possible the much-desired widespread use of desktop 3-D graphics.

The second important change in the computer industry is the tendency to miniaturize the computer, to the point that it becomes wearable on the user. Figure 2 shows just such an example, namely the Mobile Assistant IV® produced by Xybernaut Co. (Fairfax VA, USA). It consists of a CPU unit with a Pentium processor and simplified keyboard, a head-mounted display, a microphone for voice input, and a camera worn on the user's head. By coupling this with wireless communication, the user gets freedom of motion within the range of the wireless transmitter, and as a function of battery life.

User freedom of motion is very important to the VR application designer, because it increases the naturalness of the interaction, and thus the feeling of immersion that the user has. At the present time the Mobile Assistant does not have sufficient computing power to incorporate graphics real-time rendering. Such a capability is expected to appear in subsequent models of the device.

Figure 2: Mobile Assistant IV® wearable computer. Courtesy of CAIP Center, Rutgers University. Reprinted by permission

3. Graphic Displays

Another important component of VR systems are the graphics displays, which present the computer, rendered scene to the user. Such displays may be classified as personal displays, for a single user, and large-volume displays, which allow several users to view the same scene in a given location. Both types of displays have advanced significantly in the past decade, as will be described next.

3.1 Personal displays

The most prevalent type of personal display available in the nineties were head-mounted displays (HMDs), which projected the image close to the user's head. Early HMDs were very bulky and heavy, weighing over two kilograms in the case of the VPL "Eyephone." Their resolution was poor (360×240 pixels) owing to the LCD technology of the time. Compared to this, modern HMDs, such as the SONY Glasstron® shown in Figure 3, have an SVGA resolution (832×624 pixels). The improvement in image resolution was coupled with a dramatic reduction in weight (120 grams for the Glasstron). Unfortunately, the necessary miniaturization means that the user's field of view (FOV) is small (30×22 degrees) compared to the Eyephone FOV of 90×60 degrees. Recently SONY has announced it will stop producing Glasstrons. Its logical replacement is the Olympus Eye-Trek HMD (37×22 degrees) weighing a little over 100 grams [Olympus, 2000].

Figure 3: The SONY Glasstron Courtesy of InterSense Co. Reprinted by permission

The user's natural field of view is 180 degrees horizontal and almost as much vertical. The human vision system, unlike the HMDs, has an uneven resolution over its FOV. The highest resolution is in a central "foveating area," while the retina has much lower resolution away from the foveating area. By rendering the image at constant resolution the computer essentially wastes pixels, since the eye cannot see them. Eye trackers allow computers to detect where the user focuses on an image. It is then possible to render the corresponding virtual scene in high resolution, and the rest of the scene in lower resolution. A review on the state-of-the-art in eye tracking can be found in [Isdale, 2000]. Figure 4 shows an HMD retrofitted with an eye tracker.

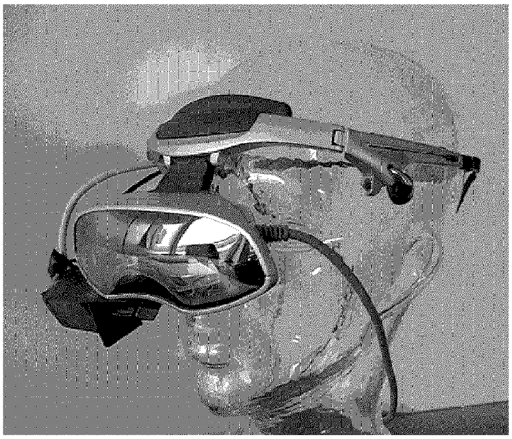


Figure 4: The SONY Glasstron fitted with an eye tracker. Courtesy of *VR News*. Reprinted by permission

Military reconnaissance training applications can benefit from a "customized" HMD, such as the V8 Binoculars (Virtual Research Systems Inc., Santa Clara CA, USA) shown in Figure 5. These binoculars integrate dual LCD displays, with VGA resolution, and a FOV of up to 60 degrees. Its optics allows individual focus adjustment, and its weight is 680 grams. By integrating a position tracker (discussed later in this report), the computer senses the 3-D aim of the binoculars and displays the corresponding scene in real time.

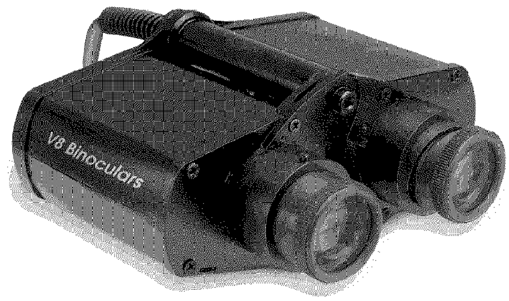


Figure 5: The V8 Binoculars HMD. Courtesy of Virtual Research Systems Inc. Reprinted by permission

Other types of graphics displays, available today, are "virtual windows" and auto-stereoscopic displays. The WindowVR® produced by Virtual Research Systems Inc., is shown in Figure 6. In has a flat-panel display (a touch-sensitive display in some versions) with handles and suspension cable. A tracker inside the display allows the computer to change the scene and give the user the sensation of looking at a virtual world through a window. Buttons on the handles allow actions and navigation within the VR simulation.

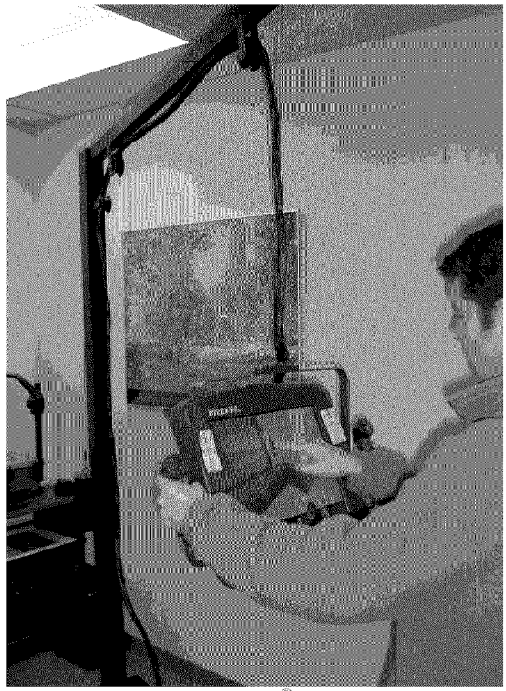


Figure 6: The WindowVR®. Courtesy of Virtual Research Systems Inc. Reprinted by permission

Auto-stereoscopic workstations, such as the ones produced by Dimension Technologies Inc. (Rochester NY, USA), use backlighting of a flat panel to produce a stereo image. As seen in Figure 7, the image appears to float in space, without the need for HMDs. Its resolution is 1280×1024, which is superior to that of LCD-based displays [Dimension Technologies Inc., 2000]. Unfortunately, the stereo image can be seen from only a small viewing volume and the brightness of the image suffers owing to the lighting scheme used. Thus graphics appears dim when compared HMDs or active glasses (discussed later in this report).

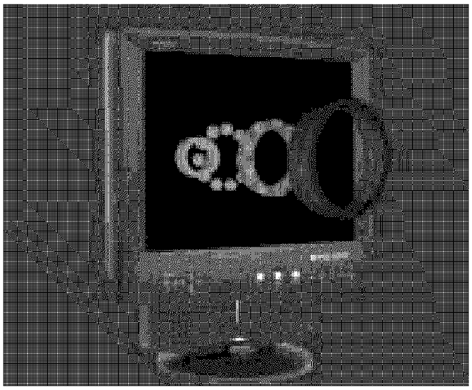


Figure 7: An auto-stereoscopic workstation. Courtesy of DTI Inc. Reprinted by permission

3.2 Large-volume displays

Large-volume displays offer a much larger stereo viewing area, high resolution, and a way for many participants to view and interact with the same virtual scene. One class of large-volume displays is "virtual workbenches," such as the one shown in Figure 8. It uses a CRT projector and mirrors to "place" the stereo scene on top of its table. The integration of its projector within the display table makes for a compact design, and the tilting mechanism can change the user's viewing cone. The Baron can tilt from fully horizontal to fully vertical, which transforms it essentially in a "virtual wall" type display. Future designs will replace the CRT technology with much brighter digital mirror technology. Then it will be possible to use such displays without having to reduce the room ambient lighting level.

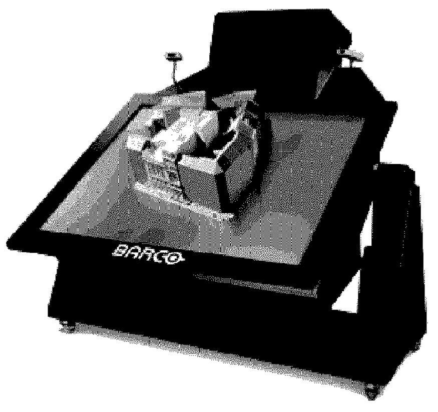


Figure 8: The BARCO Baron® 3-D display. Courtesy of BARCO Co. Reprinted by permission

Figure 9 shows a marine amphibious landing exercise scene produced by a workbench-type display [Hix et al., 1999]. The usual 2-D military symbols were replaced by 3-D icons of trucks, airplanes, ships, etc., shown on a 3-D terrain map. Such a scene is much easier to comprehend, and may reduce errors in a high stress combat situation. Furthermore, the use of 3-D icons coupled with haptics (not used in this particular training scenario) opens the way for a different kind of C&C interaction.

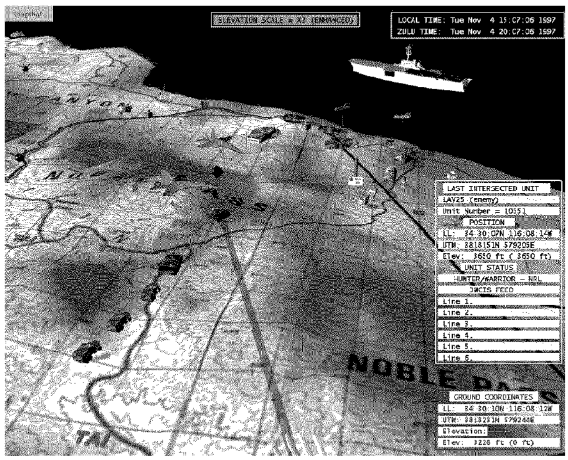


Figure 9: Sea Dragon Marine landing exercise. Courtesy of the Naval Research Laboratory, Washington DC. Reprinted by permission

Using a haptic glove (discussed later in this report) the military commander may then be able to grasp and feel such 3-D objects. The force feedback addition to the simulation has at least two important advantages for the military decision-maker. First, he knows he has complete and unique control over the unit whose symbol he grasped. This is true even if he momentarily looks away from the screen. Second, the hardness of the symbol can give him valuable information on the unit's state of readiness/strength level. A tank 3-D icon that feels soft may indicate that unit is at half strength, due to losses. A tanker plane that feels hard may indicate that it is full of fuel, etc.

An example of a C&C application using a haptic glove is the system demonstrated by the CAIP Center at Rutgers University, and shown in Figure 10 [Medl et al. 1998]. It consists of a distributed architecture, with a multi-modal interface. The user gives voice commands that are detected by a microphone array placed on top of a PC. He can select and move military symbols on a map using either an eye tracker, or a force feedback glove (Rutgers Master glove [Burdea, 1996]). The New Jersey National Guard, with little prior training, tested the system successfully in 1997.

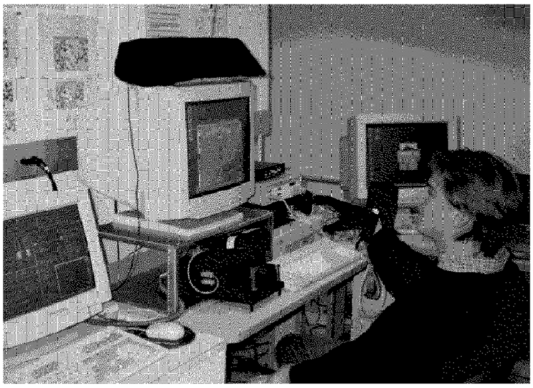


Figure 10: Multi-modal interface C&C exercise. Courtesy of the CAIP Center, Rutgers University. Reprinted by permission

A larger type of display than the workbench is the CAVE® stereo display made by Fakespace Systems (Ontario, Canada). As shown in Figure 11, the CAVE consists of multiple wall-type displays assembled in a cube geometry. Each wall has its own CRT projector, driven by a separate graphics pipe of a multi-processor high-end SGI or equivalent computer. The user enters the CAVE and is looking at the display walls through "active" stereo glasses, such as those shown in Figure 12. Infrared emitters located in the corners of the CAVE control the opening and closing of shutters incorporated in the stereo glasses. They alternately block the view of each eye, which allows the brain to register the two images rendered by the computer separately and create the stereo effect.

With his FOV filled by the graphics the CAVE user feels immersed in the virtual world. Furthermore, the work volume in which the user sees stereo and can interact with virtual "floating" objects is much larger than for a workbench. These advantages come at a price, as the cost of the CAVE is five times that of a workbench display. T this is added the cost of the high-end graphics computer, bringing the system close to one million dollars at the time of this writing.

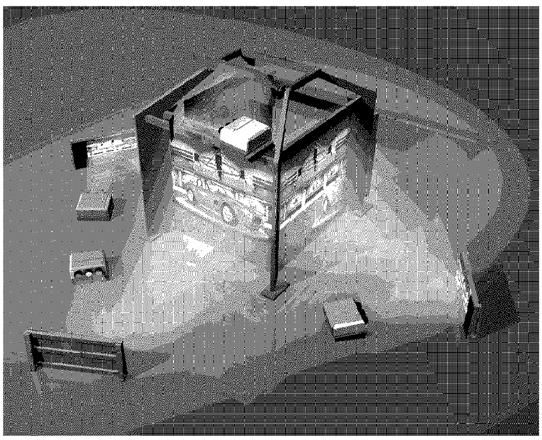


Figure 11: The CAVE stereo display. Courtesy of Fakespace Systems Inc. Reprinted by permission

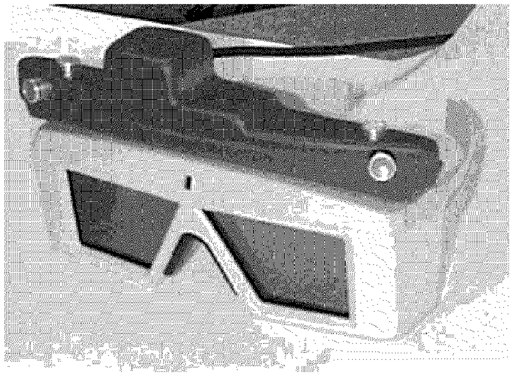


Figure 12: Stereo "active" glasses fitted with the InterSense tracker. Courtesy of InterSense Co. Reprinted by permission

Recently Fakespace Systems introduced the "Re-configurable Advanced Visualization Environment" (RAVE) shown in Figure 13. Unlike the CAVE, which has a fixed geometry, RAVE can change its configuration depending on the user's needs. Thus its 3 m × 2.9 m × 3.7 m modules can be assembled to form a straight wall geometry, where three display units are side-to-side. Other available configurations include a u-shape, or a cube (CAVE-type geometry). Alternately, it can separate itself into two half-cube independent displays. As expected, the cost of RAVE surpasses that of the CAVE.

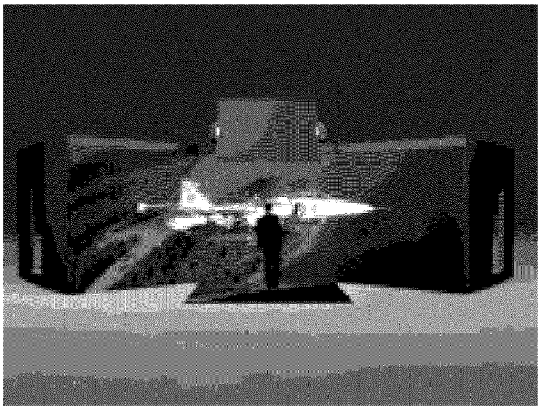


Figure 13: The RAVE re-configurable stereo display. Courtesy of Fakespace Systems Inc. Reprinted by permission

4. Large-Volume Tracking

The user's ability to see graphics that fill most of his FOV is a good start towards a more immersive virtual environment. Another important requirement is to allow the user to interact with virtual objects he sees. Thus the computer needs to know as accurately as possible the current 3-D position of the user's hand(s), head, or whole body within this large working volume.

4.1 Magnetic tracking errors

Computers determine the user's position by interpreting data fed by 3-D trackers worn on the body. The overwhelming majority of today's trackers are electromagnetic ones, consisting of a stationary source of pulsating magnetic fields, one to several receivers (coils) worn by the user, and an electronic control box. The voltages induced in the receivers are transformed in absolute position/orientation values by the control box, and then sent to the computer running the simulation.

An example of high-end magnetic tracker is the MotionStar® wireless tracking suit produced by Ascension Technology Co. (Burlington VT, USA), shown in Figure 14. The suit incorporates 20 magnetic tracker receivers placed at critical locations on the user's body, such as the wrist, ankle, hip, etc. The receivers are wired and the electronic control/communication box worn on a backpack. Owing to its own power supply (a battery with two-hour life), the suit can work independently and furnish up to 100 readings/sec. within three meters from the tracker source. Such a range would accommodate two RAVE modules, if placed side-by-side, with the source centrally located.

Figure 14: The MotionStar® wireless tracking suit. Courtesy of Ascension Technology Co. Reprinted by permission

There is however a problem with all magnetic trackers, which affects their accuracy. This is due to interference from other magnetic fields, or from metallic objects. Such problems were reported with the MotionStar® [Marcus, 1997], but also with the Polhemus LongRanger® (Colchester VT, USA) [Trefftz & Burdea, 2000]. Figure 15 shows the magnitude of the error vector for a LongRanger® installed on a wooden tripod in the Human-Machine Laboratory at Rutgers University. The tripod allowed the height of the tracker source to be varied, while precise position of the receiver was measured mechanically. The errors grew geometrically with the distance from the tracker source, as expected. However, errors also varied depending on the source height above the floor. The most accurate measurements were obtained when the source was at 1.68 m above the floor. Errors grew when the source was too close to either the ceiling or to the floor, owing to the metallic beams used in the laboratory room construction. Additional experimental measurements showed that the metal in the large-volume display (in this case a BARCO Baron workbench) introduced more tracking errors.

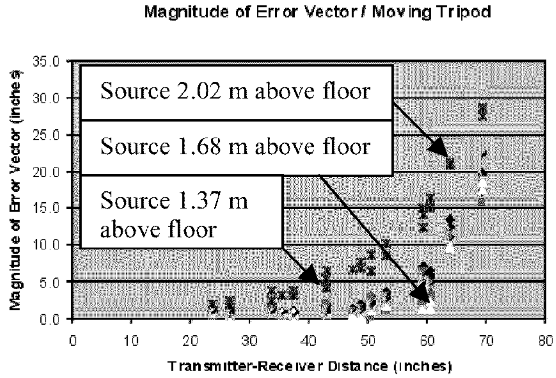


Figure 15: The Polhemus LongRanger tracking errors [Trefftz & Burdea, 2000]

The above findings, and those of others, point out the inadequacy of magnetic trackers when working in typical large-volume display environments. Thus one is left with two alternatives. The first is to build a special structure, designed from the start to house large-volume displays and the related trackers, and to redesign the display to reduce the amount of metal. The second, and an easier alternative, is to change the tracker.

4.2 Inertial/ultrasonic trackers

In recent years a new generation of trackers has become commercially available. These are hybrid 3-D position trackers, such as the IS-600 shown in Figure 16, manufactured by InterSense Inc. (Burlington MA, USA). They use a combination of inertial and ultrasonic sensing technology, with the inertial component used for position measurements, and the ultrasonic component used to provide a zero position and to correct for drift. One or more inertial cubes are placed on the user, or on his interface, together with sonic disks (as previously shown in Figure 12 for active glasses). The inertial cube signal is read by an electronic box, which also drives ultrasonic receivers placed on the ceiling in a cross configuration. Since these trackers do not use magnetic fields, they are immune to the type of interference associated with magnetic trackers.

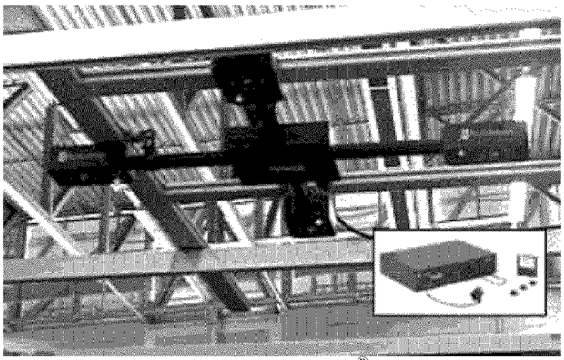


Figure 16: The InterSense IS-600® inertial/ultrasonic tracker. Courtesy of InterSense Co. Reprinted by permission

A recent addition to the InterSense tracking family is the IS-900 LAT (large-area-tracker) [InterSense, 2000]. It can extend its 6 m × 6 m × 3 m standard tracking volume to a maximum tracking area of 900 m^2 using up to 24 expansion hubs. Its measurement accuracy, resolution and latency are better than for magnetic trackers.

5. Haptic Interfaces

Another important change taking place in current VR technology is the addition of haptic feedback, namely tactile and force feedback. Tactile feedback gives the user the ability to touch and feel the smoothness of virtual object surfaces, their temperature, slippage, and contact surface geometry. Force feedback conveys information on object weight, inertia, mechanical compliance, degree of mobility, viscosity, etc. The addition of haptic feedback clearly increases simulation realism in general. Furthermore, haptic feedback allows object manipulation in occluded, foggy or dark virtual environments, a task that would otherwise be difficult or even impossible to complete.

5.1 General-purpose haptic interfaces

Haptic interfaces may be classified as general-purpose ones, which can be used for many tasks (including military ones), and special-purpose haptic interfaces, which are designed specifically for military applications.
An example of a general-purpose force feedback interface is the PHANToM® arm Desktop produced by SensAble Technologies Co. (Woburn MA, USA), and shown in Figure 17. The interface measures the position and orientation of the stylus 1000 times/sec, and applies forces of up to 10 N to the user's hand in response to actions in the virtual environment. The high bandwidth of the PHANToM allows it to combine force with tactile feedback, such that the roughness or stickiness of a surface can be simulated as well.
A typical application developed for the PHANToM is "digital sculpting," as illustrated in Figure 17. The user is presented with a block of "digital clay," which he deforms, sculpts, polishes, using the stylus. The user feels the resistance of the material, as well as the influence of the change in virtual tool to which the stylus is mapped.

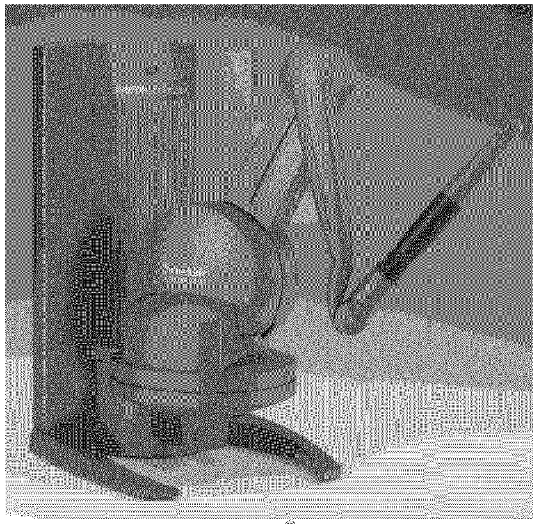


Figure 17: The PHANToM® desktop force feedback arm. Courtesy of SensAble Co. Reprinted by permission

Once the 3-D model is sculpted, its files can be downloaded to a NC mill or similar equipment, to build an actual prototype. This is also applicable to the weapon design cycle, speeding up its mock-up phase.
Another use of the PHANToM is in mine detection training, an application being currently developed by the French Ministry of Defense (see companion paper by Todeschini). The force feedback arm integrated with this system is designed to replicate the tactile sensation the trainee uses to detect a mine. Since in actual operations such a task must have a 100% rate of success, it is clear that a realistic trainer should be useful. The difficulty in realizing such a system is to realistically replicate the dynamic force "signature" associated with various mines and ground conditions.

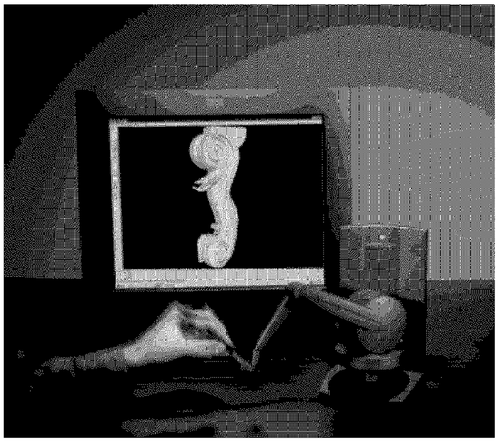


Figure 18: Digital sculpting with force feedback. Courtesy of SensAble Co. Reprinted by permission

One drawback of the PHANToM arm is that it is not able to provide finger-specific forces, such as those present in dexterous tasks, when contact is at the fingertip. Such tasks could be assembly training, servicing of military hardware, or training in explosive handling. For such instances a better haptic interface is a force feedback glove, such as the CyberGrasp® glove produced by Virtual Technologies Inc. (Palo Alto CA, USA), shown in Figure 19.

Figure 19: The CyberGrasp glove in a CyberPack configuration. Courtesy of Virtual Technologies Co. Reprinted by permission

The glove consists of a CyberGlove [Kramer et al., 1991] used for position measurements on which is retrofitted a force feedback exoskeleton driven by cables. The tendons are routed to an electronic control box housing electrical actuators and communication hardware. The force output is about 16 N per finger, which is larger than the PHANToM output. Unlike the PHANToM, which sits on a desk, and limits freedom of motion, the CyberGrasp glove is worn. Furthermore, the CyberPack® configuration places the control box in a backpack, such that the user can walk around and grasp objects and feel their hardness. Its limiting factors then are weight, (which can lead to user fatigue) and the range of the tracker measuring wrist 3-D position.

Another limitation of the CyberGrasp haptic glove is the lack of force feedback to the wrist. Thus grasped objects seem weightless, with no inertia and no mechanical restraints. Recently Virtual Technology announced the CyberForce® haptic interface shown in Figure 20. It consists of a six degrees-of-freedom force feedback arm connected to the back palm. By combining wrist force feedback with the force feedback glove, the ability to simulate weight and inertia are added while the user preserves his hand dexterity [Kramer, 2000]. Furthermore, there is no need for a wrist position tracker, since the force feedback arm measures wrist position faster and without metallic interference. Unfortunately, the dimensions of the arm limit the user's freedom of motion. Furthermore, the overall system control becomes much more complex, which may lead to system instabilities.

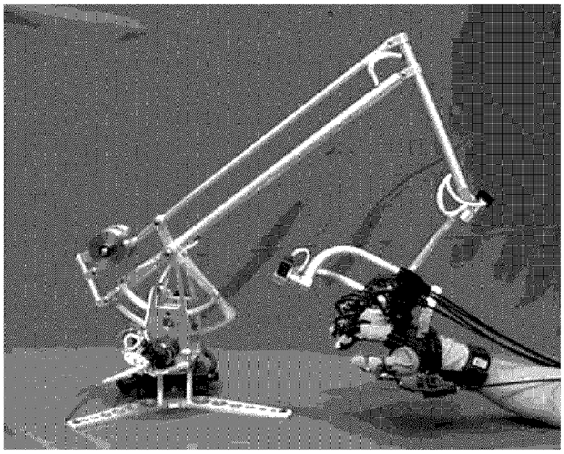


Figure 20: The CyberGrasp glove in a CyberForce configuration. Courtesy of Virtual Technologies Co. Reprinted by permission

In certain military applications of VR, such as infantry training, there is a need to simulate running, or walking uphill, or through uneven terrain. In such cases haptic feedback to the body becomes important in order to have realistic training. One system that addresses these needs has been recently developed by Sarcos Co (Salt Lake UT, USA) and the University of Utah [Hollerbach et al., 1999]. As shown in Figure 21, the user is located in front of a three-wall display filling most of his FOV and stands on a treadmill. By tracking his walking/running on the treadmill, the computer updates the virtual scene accordingly. A force feedback arm is attached to the user's torso through a harness. The arm applies resistive and inertial forces to simulate uneven terrain and other effects. A rope attached to the ceiling prevents injury in case of tripping and falling.

Figure 21: The treadport VR system. Courtesy of University of Utah CS Dept. Reprinted by permission

Recently, Japanese researchers proposed the replacement of the treadmill approach with an "active floor", as shown in Figure 22 [Noma et al., 2000]. The floor is composed of modular actuator tiles that can change slope under computer control. The user's motion is tracked by a vision system, and the tiles actuated as needed to replicate uneven terrain. Thus, unlike the walking-in-place paradigm of treadmill systems, the active floor approach allows natural walking over the whole surface of the floor. There is no need for a force feedback arm attached to the user's back, and no need for a safety rope. The limitation in this case is the size and amount of slope that can be produced by the active tiles.

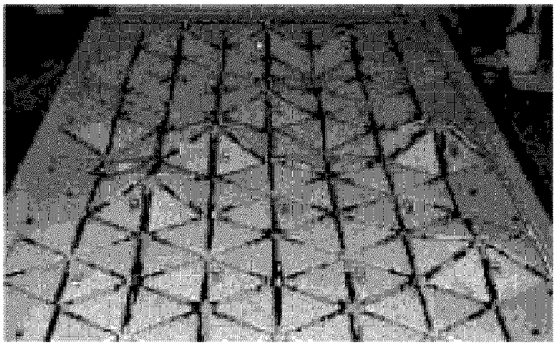


Figure 22: The active floor VR system [Noma et al. 2000]. © IEEE. Reprinted by permission

5.2 Special-purpose haptic interfaces

All the haptic interfaces presented so far are general-purpose, since they can be used in military applications but were not specifically designed for such. By contrast, special-purpose haptic interfaces are designed from the start to provide force/touch feedback to military VR tasks. An example is the Stinger trainer prototype developed at TNO (The Hague, The Netherlands) [Jense, 1993], shown in Figure 23. It consists of a plastic mock-up of the missile launcher, which is instrumented to track the user's aim, and to sense when switches are depressed. Furthermore, a virtual environment showing the enemy aircraft is presented to the trainee on an HMD. The advantage of this system is that a much more compact set-up replaces the classical large-dome training system. Furthermore, all user actions are stored transparently and his performance data is available on the computer. The force feedback sensation is produced naturally by the plastic mock-up, without need for more expensive (and heavier) hardware. The system is now being used in training the German Air Force, as described in the companion paper by Reichert.

Another example of special-purpose haptics is the anti-tank missile trainer system recently developed by the Fifth Dimension Technologies Co. (Pretoria, South Africa), which is shown in Figure 24. It uses a mock-up of the rocket launcher, similar to the TNO Stinger trainer, which provides direct tactile feedback. Other similarities include the used of a HMD to display the virtual battlefield to the trainee, and a 3-D tracker to determine his direction of view.

Figure 23: The Stinger VR training prototype Courtesy of TNO, The Netherlands. Reprinted by permission

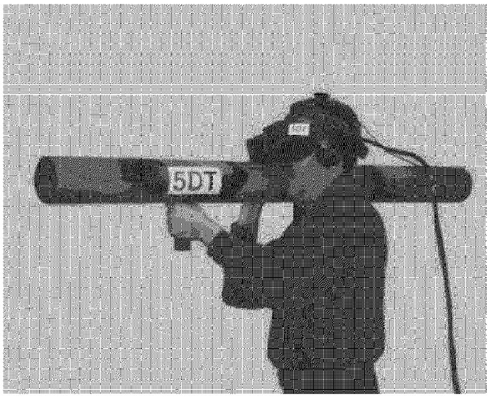


Figure 24: The anti-tank VR training prototype Courtesy of 5DT Co., Pretoria, South Africa. Reprinted by permission

Another type of special-purpose haptic interface is the parachute-training simulator developed by Systems Technology Inc. (Hawthorne CA, USA). As shown in Figure 25, the system uses a full-size parachute harness, and an HMD showing a detailed 3-D jump scene (insert). The scene moves in response to either head motion, or the toggle of the parachute harness [Systems Technology Inc. 2000]. Wind effects are added, to train the jumper in coping with adverse landing conditions. Playback of user actions and instructor actions are used to help acquire the necessary skills.

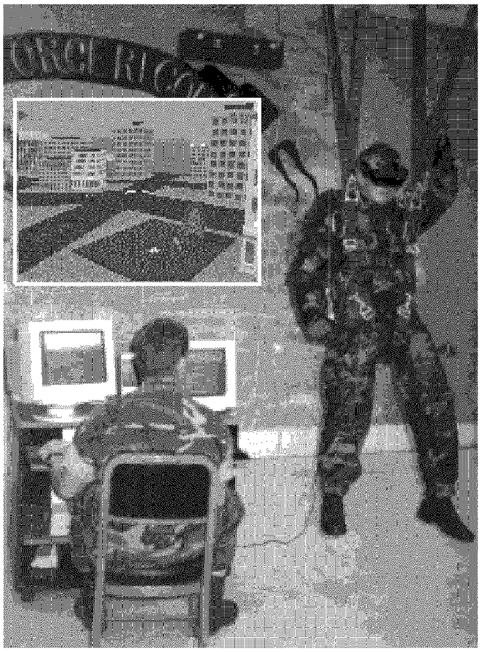


Figure 25: The VR parachute training system. Courtesy of Systems Technology Inc. Reprinted by permission

6. Modeling Tools

So far this report has reviewed the computing hardware and the interfaces available to develop VR applications. The third element needed is a VR toolkit, i.e. software libraries specifically developed for programming virtual environments. Such toolkits offer certain advantages to the developer, namely drivers for most VR I/O devices, certain 3-D graphics routines, ease of portability, etc. In turn VR toolkits can be classified as general-purpose and special-purpose libraries.

6.1 General-purpose Modeling Tools

The most used VR programming toolkit today, by far, is "WorldToolKit" (WTK), produced by Sense8, a division of Engineering Animation Inc. (Ames IA, USA). It consists of over 1000 C/C++ object-oriented functions, which are executed, in an infinite loop during the simulation. An example of a scene created with WTK is the tank interior simulation shown in Figure 26. By importing CAD files, doing smooth shaded graphics, textured surfaces, dynamic effects, WTK allows very realistic simulations to be created.

Another facility provided by WTK (in its "World-up" version) is graphics programming, as shown in Figure 27. Thus the kinematics dependencies and other virtual object characteristics can be easily specified using a scene graph. At run time the software goes through the nodes of this scene graph.

For all its advantages WTK has at least two disadvantages, namely cost and short-lived releases. The license cost for WTK is an order of magnitude more than for widespread PC software, reflecting the small market for VR products. This is aggravated by numerous releases, which many times are not compatible with earlier ones. As such a military application developed with an earlier release may not run when the library is updated (currently WTK is at release 9).

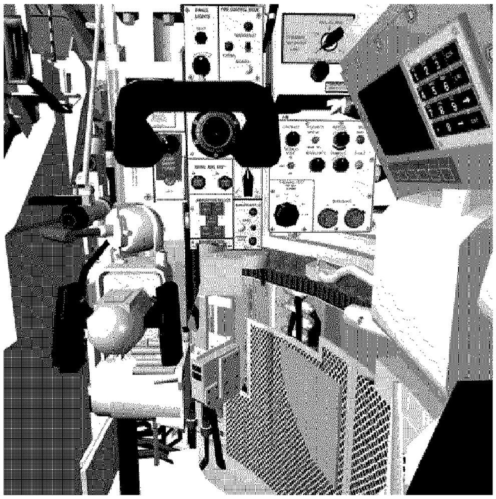


Figure 26: The tank interior created with WTK. Courtesy of EAI Co. Reprinted by permission

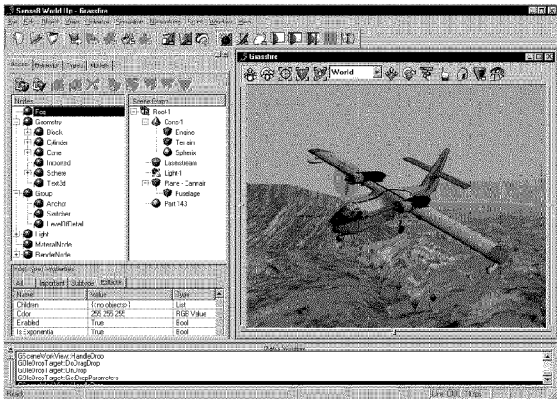
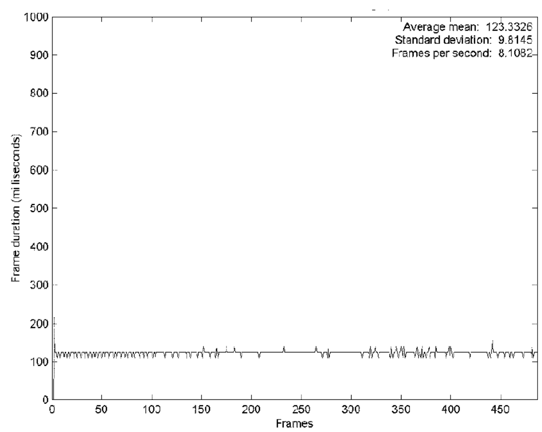


Figure 27: The World-up graph scene. Courtesy of EAI Co. Reprinted by permission

A 3-D programming toolkit which is free is Java3D produced by Sun Microsystems (Palo Alto CA, USA). Java3D programming is also based on a scene graph. However, the software is still under development, and certain drawbacks exist, when compared with WTK. One of the most important limitations of Java3D is its inability to deliver a uniform rendering speed, as uncovered by recent tests done at Rutgers University. Figure 26 [Boian, 2000] shows the same scene being rendered on a dual-processor 450 MHz Pentium PC, using (a) WTK (release 8) and (b) Java 3D (release 1.1.2). The scene consisted of 40,000 textured polygons, and collision detection was activated. When WTK was used, the average time to render one frame was 123 ms (8.1 frames/sec), with a standard deviation of about 10 ms. Interestingly enough, Java3D was 37% faster, with an average rendering speed of 11.1 frames/sec. Its average time to render a frame was only 90 ms. Unfortunately, its standard deviation was 84 ms, or 840% larger that for WTK.



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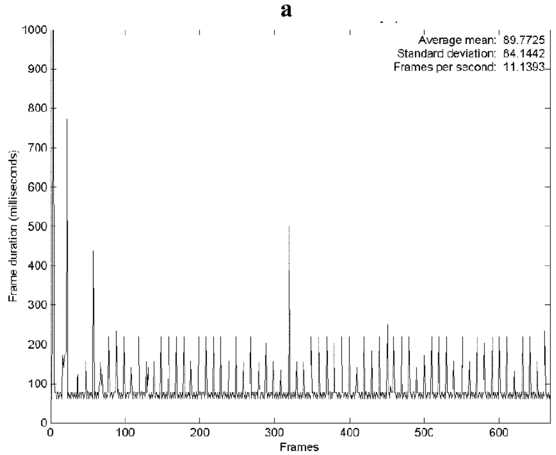

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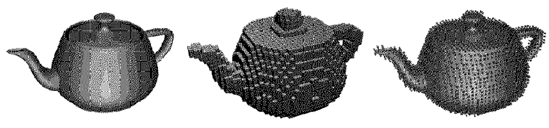
Figure 28: Comparison of frame rendering speed and consistency between: a) WTK; b) Java3D [Boian, 2000]. Reprinted by permission

Generalizations can be risky, and certainly SUN Microsystems will address some of these drawbacks in newer Java3D releases. However such large standard deviations in frame rendering time, as present in the current Java3D release will adversely impact interactions in the virtual environment, especially where force feedback is concerned.

Force feedback calculation is preceded by a collision detection step that is used by the computer to determine if there is interaction in the virtual environment. Such an algorithm needs to be both accurate and fast, which is difficult in complex virtual environments. One example is CAD analysis for accessibility. Complex assemblies, such as "crowded" aircraft engines, are difficult to design and even more difficult to service. Researchers at Boeing Co. (Seattle WA, USA) have developed the "voxel point shell" (VPS) method of collision detection to cope for such application needs [McNeely et al., 1999]. VPS builds a point shell around the surface of a single moving object in a pre-computing stage. At run time, this point shell is checked for collision with the static environment, and the resulting force/torque applied to the user. Tests done using a complex model of a Boeing 777 with almost 600 thousand polygons, shown in Figure 29, allowed haptic rendering at a constant rate of 1000 Hz. The visual frame rate was 20 frames/sec, using Boeing's proprietary "FlyThru" rendering software.



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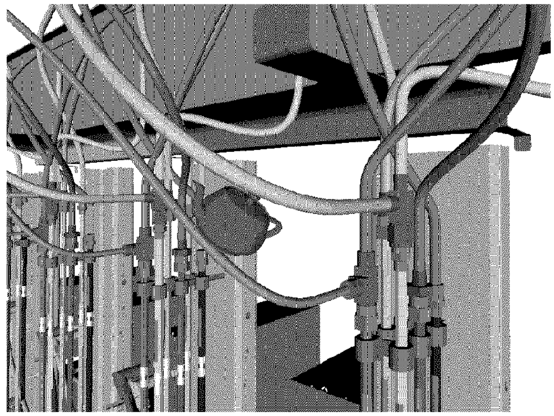

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Figure 29:

6.2 Special-purpose modeling toolkits

Special-purpose toolkits have been developed to help certain types of simulations. For example, Virtual Technologies have introduced the VirtualHand® Suite 2000, which is a library designed to work with the CyberGlove, CyberGrasp, and CyberTouch interfaces [Virtual Technologies, 2000]. It helps develop applications where interaction with the objects is at the level of the hand, and includes collision detection, a force feedback API and networking capabilities.

Another special-purpose toolkit is the GHOST library developed by SensAble Technologies for their PHANToM arm. It allows the mixing of scene graph and direct force field programming, in scenes with complexities up to 250,000 polygons (mesh configuration). Multiple PHANToM Desktop models can be supported in a daisy-chain arrangement on a single host communication port.

Finally, the DI-Guy library developed by Boston Dynamics (Cambridge MA, USA) helps program simulations involving dismounted infantry, special operations and peacekeeping operation tasks by providing an intelligent-agent based library [Boston Dynamics Inc., 1997]. As can be seen in Figure 30, the toolkit allows users to control avatars that respond to real-time task-level control. Once they are given behavior (walk, kneel, crawl, etc.) and travel parameters, they execute the action through motion interpolation. This allows multiple DI-Guy characters to be included in a given virtual scene. The toolkit is currently supported by WTK (Release 9) and by Vega (Paradigm Simulations Inc., Dallas TX, USA). Vega LynX allows a point-and-click interaction environment.

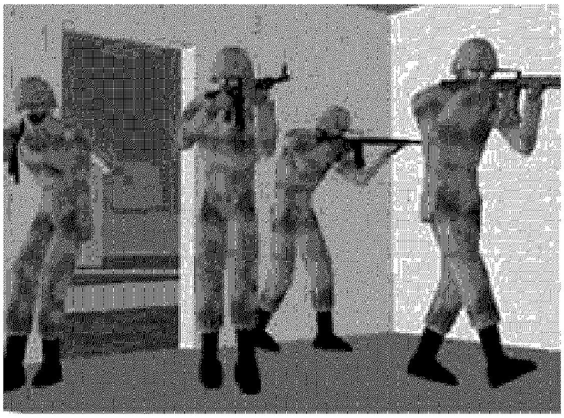

Figure 30: Scene created with the DI-Guy toolkit for dismounted infantry training. Courtesy of Boston Dynamics Inc. Reprinted by permission

7. Conclusions

There is no doubt that VR technology has been going through a rapid change. A major impact on the widespread use of this technology in the military and other areas is the tremendous decrease in computer prices, and increase in PC-based graphics speed. The miniaturization of the PC in its present form allows for portability, which results in increased user freedom of motion and simulation realism. Large-volume displays are also adding to the user ability to interact with large simulation volumes. New trackers have overcome the limitation of magnetic technology and can be used for wide area tracking and interaction. Portable haptic interfaces also add to realism, especially in tasks involving manual dexterity. Programming toolkits now offer a complex programming environment integrating the various modalities of interacting with the virtual world. All these developments point to more useful military application of VR, primarily in training, but also in C&C and weapon design/prototyping. Human factor studies need to validate the technology and its usefulness.

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