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Engineering virtual environment based training simulators

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ABSTRACT

While the potential of Virtual Environments (VE's) for training simulators has been recognized right from the start of the emergence of the technology, to date most VE systems that claim to be training simulators have been developed in an ad-hoc fashion. Based on requirements of the Royal Netherlands Army and Air Force, we have recently developed VE based training simulators following basic systems engineering practice. This paper reports on our approach in general, and specifically focusses on two examples. The first is a distributed VE system for training Forward Air Controllers (FAC's). This system comprises an immersive VE for the FAC trainee, as well as a number of other components, all interconnected in a network infrastructure utilizing the DIS/HLA standard protocols for distributed simulation. The prototype VE FAC simulator is currently being used in the training program of the Netherlands Integrated Air/Ground Operations School. Feedback from the users is being collected as input for a follow-on development activity. A second development is aimed at the evaluation of VE technology for training gunnery procedures with the Stinger man-portable air-defense system. In this project, a system is being developed that enables us to evaluate a number of different configurations with respect to both human and systems performance characteristics.

Keywords: displays, trackers, distributed interactive simulation, systems engineering, perceptual requirements, performance evaluation

1. INTRODUCTION

Right from the emergence of the technology, the TNO Physics and Electronics Laboratory (TNO-FEL) has been researching the application of advanced Virtual Environment (VE) technology to military training and command & control problems[1]. At TNO-FEL the Virtual Environment R&D program is driven by application requirements, not by technical innovations per se. This means that the requirements of specific applications determine

- the selection of available technology,
- the volume of our development efforts, and
- the direction of our background research.

In the course of our R&D activities on VE's over the past six years we have come to believe that the technology has now matured sufficiently for several training applications to become feasible, and that we have now gained sufficient experience with the development of VE systems to be able to actually *engineer* (as opposed to *hack*) real systems.

One of the focal points in our research program is the use of Head Mounted Display (HMD) technology to provide a visual environment that fully surrounds the user, the main advantage of HMD's being their much smaller size then conventional projection display devices. The use of HMD technology in virtual environments for training simulation has always been recognised to be of great potential. However, with the exception of a small number of CAE flight simulators, to date the authors have no knowledge of operational military training devices based upon this technology. One of the reasons is that it is often difficult to determine the (perceptual and training) requirements of a given application, and adequately map these on the available technical capabilities. This is exactly what we have done in the projects that will be described here.

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In the remainder of this paper we provide a description of two R&D projects, one of which has recently been completed, and another that is currently underway. In both projects we followed a systems engineering approach in the sense that we

1. Analyzed training objectives, current training tasks, and a possible future training program;
2. Analyzed perceptual requirements for each training task;
3. Determined the functional requirements for a VE based simulator to support the training program;
4. Assessed the technical feasibility of a VE based training simulator concept;
5. Identified the technical bottlenecks in the preferred simulator concept.

In section 2, this approach is illustrated by a description of the Forward Air Controller (FAC) training simulator, A concise description of FAC operations and current training practice is given, including the problems. This is followed by a more detailed description of the FAC simulator and the outcome of an initial evaluation of the prototype version. In section 3, we give an overview of a feasibility study in which we explored the possibilities of a VE based training simulator for Stinger gunnery practice, including a plan to develop a prototype Stinger training simulator for R&D purposes. We conclude with a discussion of lessons learned and implications for future work.

2. FORWARD AIR CONTROLLER TRAINING SIMULATOR

Initiated by a demand for more effective training tools at the Netherlands Integrated Air Ground Operations School (NIAGOS), the use of VE technology for training Forward Air Controllers was made subject of a feasibility study. In a co-operation between the Royal Netherlands Army, the TNO Physics and Electronics Laboratory and the TNO Human Factors research institute, a study was carried out to determine whether an HMD based training simulator would be a valid and feasible solution to improve training effectiveness.

2.1 FAC operations

The Forward Air Controller (FAC) is an army soldier who plays an important role in Close Air Support (CAS) operations. CAS operations are performed when air support is requested to attack enemy units that are in close proximity to friendly units. The task for the FAC is to guide the CAS pilots in the final stage of their mission such that they engage the correct enemy targets, without endangering friendly forces.

To accomplish his task, the FAC will choose an observation position (OP) in the terrain from where the target area can be well observed, while at the same time an unobstructed view is provided in the direction where the plane is expected to show up. From the OP, the FAC will continuously observe the enemy units, most specifically the designated target, the friendly units and (when in sight) the plane. The FAC provides guidance cues to the CAS pilot via a UHF radio connection.

In situations where it is difficult to find clear marking points in the terrain, the FAC has several ways to create artificial reference points: special light reflectors or lamps, smoke grenades and flares can be used for this purpose. Most CAS planes are also equipped to detect laser target designator signals. The FAC then uses a laser target designator to point out the target by putting the laser spot upon it.

Two types of FAC operations can be distinguished. In *low threat* operations, the CAS plane will fly into the target area at medium level (15.000 - 20.000 feet) and will then circle, usually accompanied by a wingman, above the target area for target recognition. *High threat* operations are characterised by the fact that the CAS plane will fly into the target area at a very low level, thus minimising vulnerability to anti air artillery and surface to air missiles. Not only does the pilot now operate under much more difficult conditions, the FAC also has a much more difficult task to guide the pilot onto the target.

After all mission briefing procedures have been completed, the plane will be approaching the target area at the so-called Initial Point (IP). The IP is the point where CAS pilot and FAC get synchronised. As the pilot calls "Leaving IP now", the FAC knows where the plane is and what heading it is flying at. Based upon his knowledge of the terrain, the FAC envisions the environment as the pilot should see it, and starts giving cues to guide the pilot. Usually the IP is in the order of 20 to 30 kilometres from the target position. This gives the FAC one or two minutes to brief the pilot on the target area. At 5 to 8 kilometres distance, the FAC will normally detect the plane visually. The pilot now has 10 to 30 seconds left for final control to the target. The FAC will not clear the pilot to attack unless he is absolutely certain that the pilot has the correct target in sight.

2.2 Current FAC training practice

A typical initial FAC training course currently takes three to four weeks. The first part of the course, about a week, covers theory: air operations in general, CAS operations, NATO standard FAC procedures, map handling, radio operation, radio procedures, etc. After this, the practical issues are divided into two parts: low threat and high threat operations. Most training effort is put into high threat operations. Training for high threat FAC operations is currently facilitated in three ways in addition to theoretical instruction:

- review of video and voice recordings that are taken from a cockpit during FAC operations (so-called HUD tapes);
- classroom simulation by using a scale model of a target area and a toy plane;
- live training runs.

HUD tapes and scale model simulation are only used in the first week of the course. The remainder of the course is filled with live training runs to exercise high threat training as much as possible. Low threat scenario's are usually not trained with live training sorties.

2.3 Current training bottlenecks

Analysis of the current FAC training practice shows a number of bottlenecks that reduce both the effectiveness and the efficiency of current training:

- Moving from class room training to live training for high threat operation proves to be too big a step, as witnessed by the bad results of the first series of live training runs;
- Limited availability of flying hours for live training sorties often severely impedes the training course (due to e.g., cost restrictions, capacity restrictions, flying restrictions, weather restrictions and bird activity restrictions.)
- Live training is the only effective training tool for high threat FAC operation, but it is a very expensive tool to use.

These bottlenecks have been taken as the starting point for the hypothesis that a new simulation tool will solve them, and improve both the effectiveness and efficiency of FAC training.

2.4 Simulator prototype

The essence of the FAC simulator is that it shall provide a training tool that bridges the gap between the standard classroom instruction and the live training. The simulator shall enable the FAC trainees to experience and exercise FAC procedures in a realistic way (i.e. with realistic time pressure and realistic visual perception tasks) before they are exposed to real planes. The simulator was prototyped within TNO-FEL's Electronic Battlespace Facility[2]. This distributed simulation facility, created to support the research on new training and command & control concepts, enabled us to develop a prototype FAC simulator within four months.

2.4.1 System architecture

The basic concept behind the FAC training simulator is that of a Distributed Interactive Simulation. The system consists of a network of independent simulators that co-operate within a network. Standard protocols are used to communicate between simulators. TNO-FEL's Advanced Simulation Framework software[3] was used to ensure compliance to both the DIS and the HLA standards[4,5]. Figure 1 depicts the main components that make up the FAC training simulator network. These components and related issues are described below.

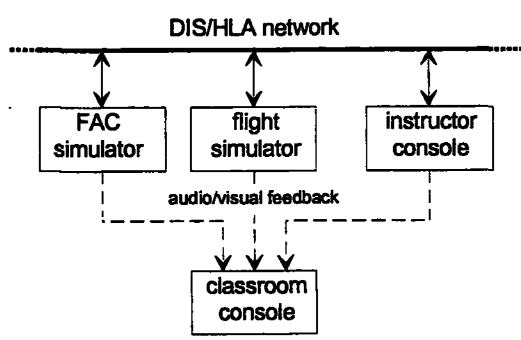

Figure 1. The conceptual structure of the FAC training simulator prototype system.

Note that the distributed simulation concept enables the incorporation of any type and any number of simulators in the FAC training simulator, while the independent simulators can be placed at different locations. This allows for a continuous growing path of the simulator for more complex scenario's and advanced applications. The prototype system presented in this paper is a minimum configuration of the FAC training simulation concept.

2.4.2 HMD based FAC simulator

The primary component of the system is the FAC simulator. An HMD based virtual environment system is used for this purpose (see Figure 2). The need for an HMD is motivated by the requirement that the FAC must be able to fully observe the environment around him, since CAS plane and target are usually in opposite direction. An HMD is advantageous over other projection displays in the fact that an it provides visual feedback covering the entire 360° azimuth and 180° elevation field of regard in a very small and affordable device. Because of this, the HMD is very suitable for tasks that rely on spatial perception of an environment, as is the case with FAC operation.

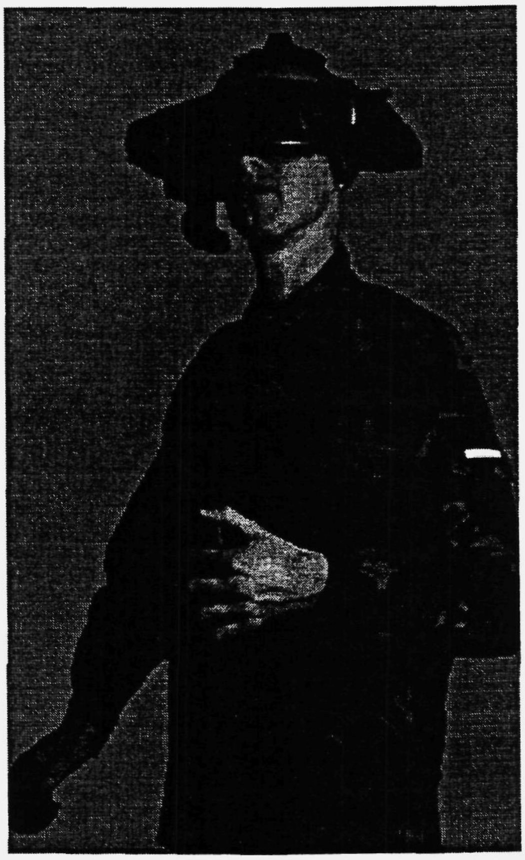

Figure 2. The FAC simulator uses a Head Mounted Display to immerse the FAC in the working environment.

The FAC simulator component is basically no more than just a visual simulator. A Silicon Graphics Onyx^2 with Infinite Reality graphics computes stereo images of the terrain surrounding the FAC and displays them through the HMD device (see Figure 3).

The HMD used for the prototype is an n-Vision HiRes stereoscopic device that displays 1280x1024 pixels in each eye. The optics of the HMD project the images onto a field of view of 63° horizontally by 34° vertically per eye, with a 50% overlap between the two images. This yields a resolution of 1,6 arcmin per pixel. The HMD is tracked by an InterSense IS-300 PRO tracking device that continuously reports the viewing angles of the FAC trainee. The IS-300 uses inertial technology to determine the FAC's viewing direction.

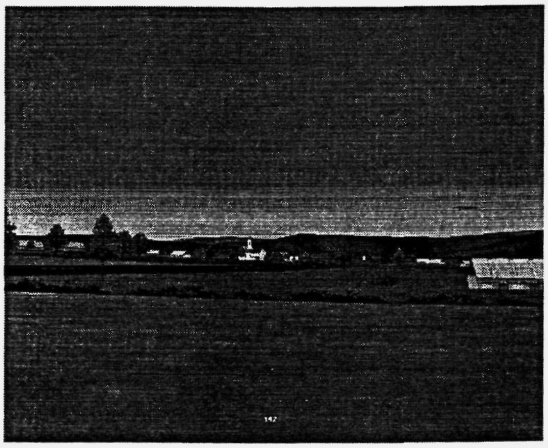

Figure 3. A view on the simulated terrain as seen through (one eye of) the HMD.

2.4.3 Flight simulator

The flight simulator used in the prototype incorporates a very simple flight model that is controlled by stick and thrust controls. The pilot has a standard monitor on which the terrain is visualised. The display also includes a simple Head-Up Display with basic navigation and aircraft status indications. For initial FAC training, the flight simulator must be no more complex than required to achieve the FAC training objectives, i.e., the FAC is being trained - not the pilot.

2.4.4 Instructor console

The instructor console provides all scenario management and instruction management functions. The prototype instructor console has only limited functionality (see Figure 4). It includes a map view on the training area and allows for interactive creation, modification, storage and execution of scenario's. During scenario execution, the simulation entities are traced on the map view. The console also includes functions to freeze scenario execution and to replay a scenario.

The prototype instructor console has a built-in capability to generate enemy and friendly units. This function would normally be implemented by a dedicated Computer Generated Forces (CGF) application that connects to the DIS/HLA network.

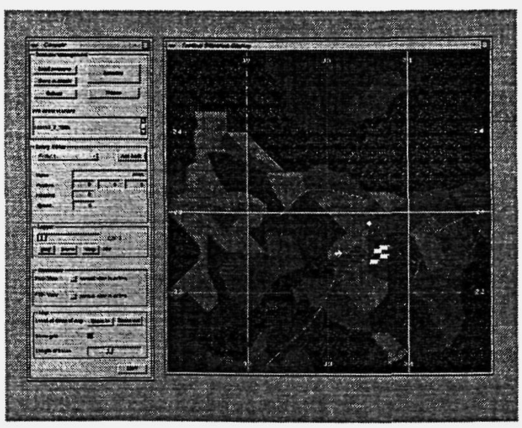

Figure 4. The instructor console display.

2.4.5 Classroom console

The classroom console is a very important component of the simulator system from the educational point of view. This component provides direct feedback on the course of action during scenario execution. This includes the view as seen by the FAC, the view as seen by the pilot, and the map view with the entities shown as moving icons. Along with this visual feedback, the console also provides audio facilities to render the radio communication. The prototype simulator includes a set of three Barco 800S retrographics projectors. The video sources are taken directly from the FAC simulator, the flight simulator and the instructor console that shows the map view.

2.4.6 Terrain database

The terrain database is a crucial component of the entire system. The database should fulfil the following requirements:

- incorporate a very detailed target area that has suitable terrain characteristics that can be used as visual cues for FAC operation;
- be large in extent to allow for fast flying planes to fly in from realistic distances;
- incorporate enough variety to facilitate a full FAC training course without running into scenario recognition problems.

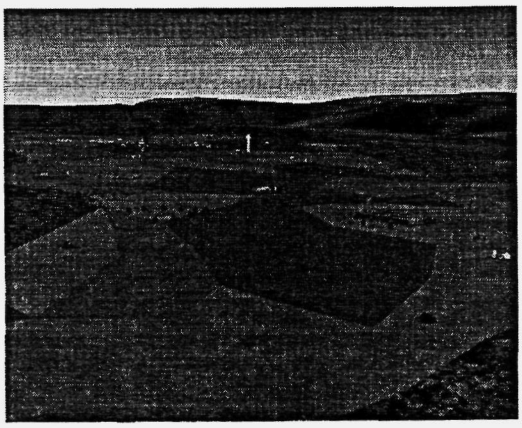

Figure 5. A view into the terrain database from the pilot's position.

The terrain database used during prototype evaluation consists of a 50km x 50km area that is defined by a terrain profile with a single texture to define the visual terrain characteristics. In the centre of the database, a detailed 4km x 4km target area is modelled that includes many terrain types, forests, roads and buildings (see Figure 5). The database complexity allows the visual systems to render images at 30 Hz for the HMD and at 60 Hz for the flight simulator.

2.4.7 Radio simulation

A voice communications system is required to simulate the use of a UHF radio connection between the FAC and the pilot. Also, it is required that the instructor can talk to the FAC trainee and the pilot during scenario execution. The prototype employs an ASTi Digital Audio Communication System (DACS) to perform all audio functions. This is a PC-based audio processing system that is capable of audio recording and playback and all sorts of audio synthesis. A hard-wired audio network was used to connect the headsets directly to the DACS system. This would in the future be changed to use the DIS/HLA network to transport the audio, thus increasing networking flexibility.

2.5 Prototype evaluation

After development of the prototype simulator an initial evaluation was performed in collaboration with the FAC school. The evaluation is limited in the sense that it has been mainly qualitative in nature. A number of issues require further evaluation and quantification. However, the evaluation that has been performed enables us to answer the main question of this feasibility study, namely whether the HMD based FAC training simulator can be an effective tool to resolve current FAC training bottlenecks.

2.5.1 Evaluation method

Prototype evaluation has been done in five sessions. In the first two sessions, only FAC instructors were involved, whose primary aim it was to assess whether it is at all possible to simulate FAC operations with the simulator, and secondly whether the system is a suitable as a instruction tool. After a positive outcome of the first two evaluation sessions, the prototype was to be further evaluated in three regular FAC courses as given by NIAGOS. The objective of these sessions was to determine how inexperienced trainees would cope with the system and what the learning transfer would be. In the first week of the course, after trainees had caught up with theory, simulation training was performed during a single day. Practical constraints limited the use of the simulator to only a single day per course - ideally the simulator should be used during the whole course.

2.5.2 Evaluation results

The main outcome of the evaluation sessions is that the FAC simulator proves to be a valid simulation of FAC operation and that it can be used effectively to improve FAC training. This is based on the following observations:

Improved training effectiveness: The use of the FAC simulator enhances training effectiveness. Taken into account that only a single day of simulator training was integrated in the course, it was already observed that the initial live training runs after simulator training were more successful than in courses without simulator training.

Improved training feedback: The use of a classroom console has proven to be a very valuable instruction tool. The correlation of the FAC's view with the flight simulator view in particular provides trainees good insight in how a pilot perceives the terrain, thus learning which cues are best used for visual guidance. The use of the *scenario freeze* and *scenario playback* features also demonstrated the value of simulation over live training. During live training, there is little opportunity to evaluate runs. Simulation, on the other hand, allows direct feedback on the trainees behaviour.

Improved training flexibility: Having the control to fly sorties in the simulated world at any desired time, any desired place, and in any desired pattern has proven to be a relief for FAC instructors. Current FAC courses are continuously impeded by uncontrollable variables like weather, birds, mechanical problems with planes, etc., which are fully controlled in the synthetic training environment.

Human performance issues: Several important human factors issues have been observed during the evaluation sessions of the prototype:

- all trainees accept the HMD based simulator as a useful tool - no simulator sickness or discomfort were reported;
- to obtain visual aircraft detection ranges that are realistic (5 to 8 kilometres), the aircraft model is scaled up 8 times (and gradually scaled down to a 1:1 size as it approaches the FAC);
- trainees are indeed able to give visual guidance control to the pilot by perceiving the plane's position and orientation;
- trainees have some difficulties in getting the right orientation within the terrain (this problem has been reduced by displaying a heading reading at the bottom of the screen).

Technical issues: From a technical point of view, the experiments with the FAC simulator prototype have taught us the following lessons:

- The InterSense tracking system is superior over often used electromagnetic tracking systems, considering both accuracy and speed - a comparison between the two has shown considerably improved perception capabilities for target detection, due to absence of lag and jitter;
- A large amount of system development effort will have to go into database development - a diversity of high quality databases is a prerequisite for a fully operational training simulator;
- The distributed architecture of the FAC simulator, relying on the standard DIS/HLA concepts, provides ample opportunities for the development of a fully functional and extendible simulator.

A more formal validation of the FAC simulator is planned to take place in March 1998, when the simulator is scheduled to be used in two training courses at the Joint Forward Air Controller Training and Standardisation Unit (JFACTSU) at RAF Leeming, UK.

3. STINGER TRAINING SIMULATOR

Several years ago we developed a technology concept demonstrator for a VE based Stinger training device[1]. The objective of that system was merely to indicate the potential benefits of VE technology for this type of applications, in particular for its use in low-cost, transportable training aids in addition to the existing Stinger training facilities. In contrast, the project described below involved an extensive analysis of current training practice and devices to assess the need for additional training equipment, and the feasibility of using VE technology to fulfil an actual training requirement[6].

3.1 The Stinger weapon system

Essentially, Stinger is a man-portable air defense system (MANPADS), incorporating a shoulder-fired, infra-red homing (i.e., heat seeking) guided missile system. It is mainly used for point defense against high-speed, low-level aircraft and helicopters. The system is operational with the Royal Netherlands Army, Air Force, and Marine Corps, and the armed forces of many other nations.

3.2 Stinger operations

Typically, incoming aircraft are detected by either a Stinger team commander or gunner at a distance of about 4 km. Upon detection, the commander assigns the target to a gunner, who activates his weapon. Target identification is done visually or through an Identification Friend or Foe (IFF) system. The commander then issues the "engage" command or cancels the rest of the procedure. Given the average detection distance, aircraft speed, and times it takes to take the above mentioned steps, the gunner will have to engage the target within 11 seconds after target detection.

3.3 Current Stinger training facilities

Target detection, aiming, target tracking, and firing are currently trained in the STinger Trainer (STT), a dome-type simulator of 20 m diameter. STT allows two real-time computer generated targets to be projected against a static terrain background. Instructor support is provided for trainee performance analysis and scenario management. Both development costs and operational costs of the STT are very high, whilst its capacity is limited. Motivated by this, the RNL Air Force requested us to perform a study aimed at assessing the need for additional training facilities. The study involved an analysis of training objectives and tasks, perceptual requirements analysis, functional requirements definition, system architecture definition, and technical feasibility assessment.

3.4 Current training bottlenecks

The outcome of the training analysis phase of the project was that the current Stinger training program of the RNL Air Force exhibits a number of bottlenecks, two of which are relevant in view of the potential use of VE technology.

Proficiency upkeep After initial training and certification, Stinger gunners and team commanders are deployed to one of four geographically dispersed air bases in The Netherlands. The logistical requirements of periodically bringing them back to the single central training simulator facility severely limits the possibility for proficiency upkeep training.

Team training The RNL Army Stinger tactics have a team of 1 commander plus 2 gunners located within a few meters of each other. The Air Force on the other hand operates with the 2 gunner located up to 50 meters away from the commander. This situation cannot be trained in the STT dome simulator due to lack of space.

3.5 Perceptual requirements

After analysis of the different training tasks, a number of perceptual requirements can de derived. These can be classified in two categories, one related to visual tasks, and one related to visuo-motor tasks.

Visual tasks that were identified include the following:

- Visual search: Using slow horizontal and vertical scanning movements of the head, both commander and gunner scan a 60°×60° sector of the sky to search for targets. Targets usually appear within the central 45° of the central Field Of View (FOV).
- Target detection occurs in the peripheral FOV, which sets a lower limit to the required relative flux in the image. Precise target shape is of secondary importance here, as is color information. A "guesstimate" as to the required resolution turns out to be around 7 arc minutes.
- Target recognition requires a certain minimal resolution of the display, which was initially determined to be in the order of 0.3 arc minute. The use of color at this stage is unclear.
- Distance estimation depends on changes in the relative flux, object orientation, and type classification, which in turn specifies the required resolution.

- Size estimation is done by comparing the target visually with the size of a fixed range ring in the weapon's aiming sight.
- Orientation of the target is relevant for determining the flight path, which in turn determines the correct engagement procedure, e.g., lead angle during aiming;
- Direct visual and auditory communication between team members would require large FOV of the display system.

Visuo-motor tasks that are essential for correct simulation of weapon handling tasks include

- Lifting and handling of the weapon, which involves direct visual and haptic feedback, i.e., physical contactc with the weapon round and grip stock;
- Lining up the aiming sight is highly critical and involves positioning the eye with respect to the exit pupil of the aiming sight;
- Aiming and target tracking are highly sensitive to temporal disturbances that might occur in a simulator such as transport delay or tracker jitter.

An additional requirement is that for long training sessions, which in practice can take longer than 30 minutes, situational awareness and visual comfort are critical to prevent any adverse effects.

3.6 System architecture

In view of the outcome of the training analysis phase of the project, the system architecture should address several important requirements:

- The simulator shall support both individual and team training;
- It shall also be suitable for mission rehearsal and other large scale exercises;
- The simulator shall be extendible.

These requirements almost automatically lead to a distributed approach, similar to that of the FAC training simulator, i.e., an architecture, based on the DIS/HLA infrastructure interconnecting a number of different components such as:

- one or more VE based gunner simulator(s);
- a VE based commander simulator;
- a target generator;
- an instructor station.

Depending on future requirements, such an architecture can easily be extended to include other simulators for e.g., higher echelon air-defense assets (Hawk, Patriot), peripheral equipment (early warning radar), or other Computer Generated Entities to "round-out" the battlefield for mission rehearsal and tactics training.

3.7 Technical bottlenecks

A number of technical bottlenecks can be anticipated for a VE based Stinger trainer that should address the functional and perceptive requirements mentioned above. Here we will limit ourselves to discussing the ones that are directly related to the use of VE technology, i.e. display format, display quality and ergonomic aspects, tracking, and simulation of the Stinger weapon, own body, and other team members.

3.7.1 Display format

There are essentially three options for the display format:

- see-through HMD
- immersive HMD
- projection screen

See-through HMD's are best suited to meet many of the perceptual requirements specified in section 3.5. However, immersive HMD's are the best choice from a technical requirements point of view, their major advantage being that they make the system very flexible with respect to environmental requirements, because they completely isolate the trainee in a computer generated world. Also, there are no problems in this case with mutual occlusiòn of virtual and real objects as in the case of see-through devices. A large disadvantage of both HMD types is that they preclude the physical contact between the gunner's head and the aiming sight, which may be essential for proper performance of several of the training tasks. Some form of projection display should therefore not be precluded.

3.7.2 Display quality and ergonomics

To be able to meet the perceptual requirements of as many of the visual and visuo-motor tasks mentioned in section 3.5 a trade-off analysis will have to be made of available display devices with respect to brightness, contrast, field of view, and spatial resolution. Several options can be ruled out from the outset, e.g. see-through HMD's based on raster displays in the "open field". Because of brightness and contrast limitations such devices require a specially prepared operational environment. As far as resolution is concerned, the current state of the art is embodied in the CAE Fiber Optic Head Mounted Display (FOHMD), which provides a background resolution of about 5' over a 130° horizontal FOV (albeit at a cost of US$ 1M.) This is marginally sufficient for e.g. target detection.

3.7.3 Tracking

Aiming the Stinger in a synthetic environment requires the fast and accurate measurement of position and orientation of both the weapon and the gunner's head. The combination of both is especially sensitive to inaccuracies and instabilities of the tracking system. Latency in the tracking system in combination with transport delays of the system simulation and the image generator can cause perceptual problems or even the inability to achieve the desired training transfer. Total transport delay, including the tracking system, of a VE based Stinger simulator should certainly remain below 50msec, and possibly even lower. The maximum allowable orientation error is of the order of 1'.

3.7.4 Other technical bottlenecks

When using an immersive HMD, the gunner will manipulate a "dummy" weapon consisting of only the most essential mechanical elements required for correct haptic feedback. The virtual Stinger weapon will have to be visualized by the image generator. Because the gunner is in very close proximity to the weapon, a highly detailed weapon model is probably required, taking a large slice out of the polygon budget of the virtual environment. A further point is modeling the aiming sight: this consists of two elements, the reticule, positioned at about 2cm in front of the gunner's eye, and the range ring at a distance of about 25cm. It remains to be determined if the fact that these cannot be projected at different focal distances in an HMD in any way influences the visual aiming task for the gunner or not.

Visibility of the gunner's own body may be required for the "lifting and handling" task. A see-through HMD and a projection display allow the trainee to see his own body at all times, but for an immersive HMD a computer generated rendering of a virtual body may have to be provided. In addition to this, the amount of detail required for visualizing other team members, as well as the way in which their behavior should be simulated will also have an impact on the performance requirements of the system.

3.8 Recommendations

The following technical bottlenecks have been deemed essential:

- Selection of the display format;
- Determining and controlling the total transport delay of the system, primarily the tracking and image generation subsystems;
- Determining the accuracy and stability of the tracking subsystem.

Each of issues bottlenecks will have to be solved to the extent that an adequate performance of the essential visual and visuo-motor tasks can be accomplished. In order to reach a solution for each of these problems at an early stage, a prototype Stinger simulator with limited functionality should be developed, that allows experimental evaluation of various alternative solutions. Development of such a prototype is scheduled to start in the summer 1998.

4. CONCLUSIONS

We have described a systems engineering approach to developing training simulators based on virtual environment technology. The steps involved in the development process include:

- Training analysis to determine training objectives and training tasks;
- Analysis of perceptual requirements for the various training tasks;
- Determining the functional requirements of a training simulator that meets the training requirements;
- Designing a system architecture based on the functional requirements;
- Assessing the technical bottlenecks involved in meeting the perceptual and functional requirements.

This process has been illustrated by two examples. The first is a training simulator for Forward Air Controllers, that relies on the active visual exploration of a virtual environment in combination with the accurate use of radio communication procedures. This simulator has actually been developed and evaluated. The second example is a simulator to train Stinger gunnery practice. This simulator will also require interactive manipulation of the virtual environment, and is therefore much more complex than the FAC simulator. The initial phases of the system development process have yielded several critical technical bottlenecks. The development of a research prototype simulator is planned in order to evaluate alternative solutions to these problems prior to starting the development of an operational trainer.

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