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TITLE

TOW VIDEO INTERACTIVE GUNNERY SIMULATOR \(TVIGS\)

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TOW
VIDEO INTERACTIVE GUNNERY SIMULATOR
(TVIGS)

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ABSTRACT

This report describes a prototype training device for TOW 2 gunners. The TOW Video Interactive Gunnery Simulator (TVIGS) was developed by DCIEM to demonstrate the application of an interactive video system invented to train operators of direct fire weapon systems. The system capitalizes on commercial video products and microcomputer technologies to achieve perceptual fidelity at low cost. Lessons learned from previous research and development efforts investigating the efficacy of a videodisc-based trainer for tank gunnery were applied to the design of the TVIGS prototype. The system makes use of an operational traversing unit and tripod and a modified spent missile round. It is applicable to TOW under armour. The approach could also be used for other direct fire weapon systems.

The key component of the device is its visual system. Video imagery from a variety of sources can be used for gunnery training. Thermal scenes can be simulated and fog and smoke can be superimposed upon background video imagery. Sound effects also accompany training. Student actions are automatically recorded and instructors can control and monitor student progress. Interactive crew (detachment) training is possible.

INTRODUCTION

The Infantry of the Canadian Forces is responsible for advanced defence against enemy armour. Its principal weapon is the tube-launched, optically-tracked, wire-guided (TOW) missile system manufactured by Hughes Aircraft Company. This man-guided missile can be launched from a tripod, personnel carrier, or armoured fighting vehicle. It is guided to the target by electrical signals carried along two thin wires that spool from the rear of the missile. A distinguishing feature of TOW 2 is that it has a thermal imagery (TI) sight.

The major tasks of a TOW gunner include the following: arming the missile, detecting, recognizing and identifying targets, firing the missile, reacting appropriately to the effects of smoke, noise and overpressure on launch, and steadily tracking the target for the duration of its flight (up to 16 secs). As well the gunner must continuously assess the tactical situation for targets of higher priority, take account of physical obstructions which would jeopardize success, react quickly to misfires and erratic flights, and perform post engagement procedures.

Several factors limit the effectiveness of live firing as a means of providing training on these tasks. Among these are the high cost of live rounds, the concern for safety, the availability and environmental damage to ranges, poor weather conditions, inappropriate targetry and a lack of objective means for assessing gunner performance and for providing immediate feedback on other aspects of the engagement.

The principal training devices for TOW now include the M70 Training Set and the Moving Target Simulator Training Set. The M70 is used outdoors. The Moving Target Simulator Training Set is an adaptation, developed by DREV, for indoor use. The indoor system is manufactured by Gentec Inc., in Montreal. Descriptions of these devices and their deficiencies are provided elsewhere [1, 2].

In July, 1985, DCIEM was tasked by the Director Land Armament and Electronics Engineering and Maintenance (DLAEEM) on behalf of the Anti-Armour/Light Armoured Vehicle Project Management Office (PMO AALAV) to develop an interactive video system for direct fire weapon system trainers and to demonstrate the application of the technology to the development of a training simulator for TOW 2. The purpose of this report is to describe a prototype TOW 2 Video Interactive Gunnery Simulator (TVIGS) and to document the principles guiding its development.

SYSTEM DESCRIPTION

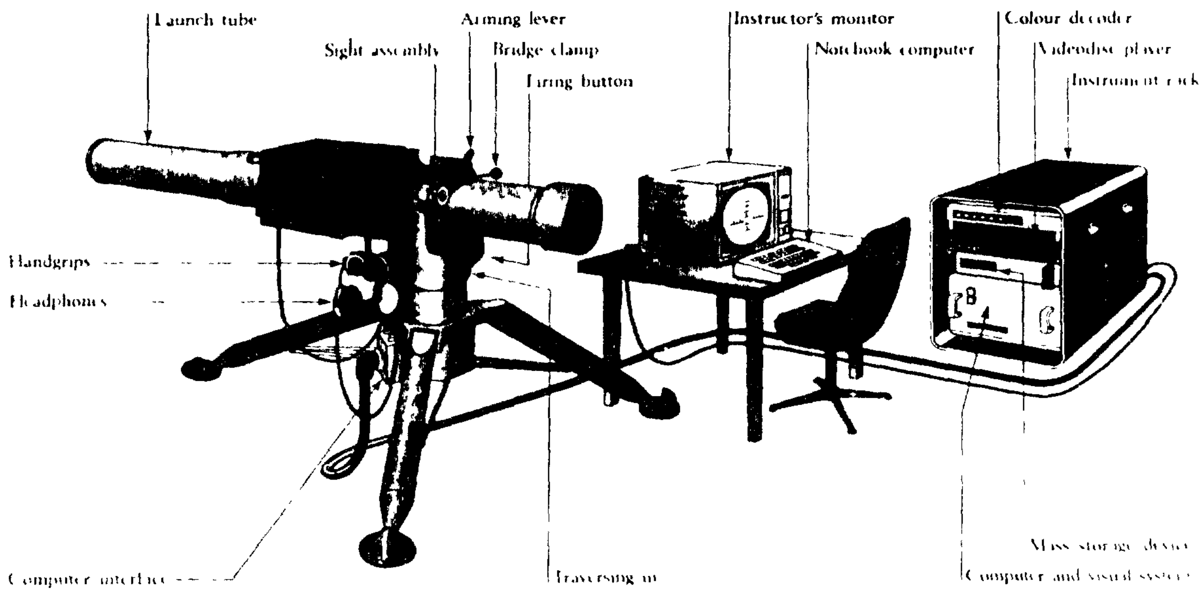
Overview

Figure 1 illustrates the system's main components. These include an interface to the traversing unit, a visual display sight assembly, headphones, an instrument rack, an instructor's station consisting of a monitor and notebook computer, and wiring harness. The major electronic components, including the main computer system, are housed in a shock-mounted, water-proof instrument rack. Removable front and back panels (not shown) enclose the rack for transport. The system is integrated with operational components. These include a launch tube, traversing unit and tripod. A modified, spent missile cartridge is also used. The optical sight, night sight and digital missile guidance set are not used, avoiding wear of the most costly components of the TOW 2 system. The TVIGS is intended for unlimited use by a trainee.

The principal goal of the TVIGS prototype is to demonstrate a means of providing realistic training and performance assessment at low cost. This is achieved by the use of commercial video products and microcomputer technologies. Video recordings of different types of targets, static and moving, on various types of terrain are shown to the gunner through the sight assembly. Several missiles can be fired at one or more targets during a training scenario. The video recordings are stored on a videodisc and presented on a small colour television visible through the eye piece. Cross hairs are seen within a circular field-of-view. The small electrical signals which are generated by the azimuth and elevation rate tachometers inside the traversing unit whenever the gunner changes his line-of-sight are conducted by an umbilical cord to a computer interface. Normally, these electrical signals would feed into the TOW 2 digital missile guidance set. Instead, they are converted to digital signals and passed to the computer system which includes a video processor and graphics modules. These scroll and pan the video imagery in accord with control movements made by the gunner. As a result, the gunner experiences a visual illusion that simulates the visual conditions that would accompany aiming actions using the real equipment outdoors. A key feature of the system is its dynamic response. The time delay between the initiation of a control movement and reaction by the visual display is about 33 msec. Consequently, no throughput delay, or transmission lag, is perceived by the gunners.

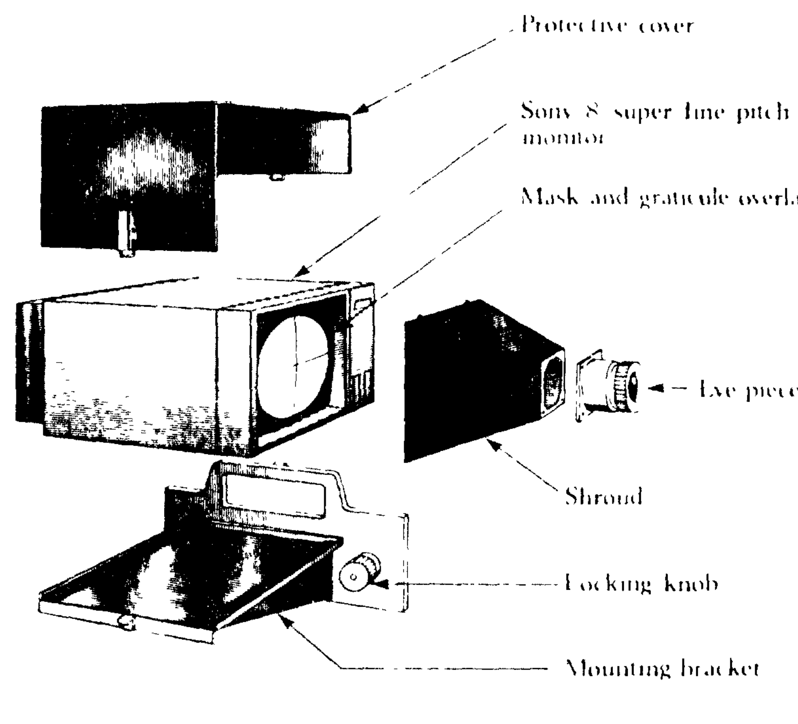
Signals conveying the switch positions for the firing button, arming lever and bridge clamp interlock, and missile present indicator are also transmitted to the interface unit so that targets can be engaged following normal procedures. When the missile is armed and fired, visual effects due to smoke, rocket motors, beacon and fall-of-shot are simulated. This is accomplished with computer generated imagery superimposed upon the video scene. Other visual effects can also be introduced. Fog can be added to the scene or a normal day scene can be transformed to simulate a thermal image.

Figure 1



TOW SIMULATOR

Figure 2



SIGHT ASSEMBLY

In addition, sound effects are provided that simulate the sounds of the gyros, the launch motor, flight motor and warhead explosion. Headphones with an adjustable volume control located on the interface, allow the gunner to hear the sound effects. The flight equations used in the TVIGS software approximate those of the TOW 2 missile, but can be modified easily to simulate basic and improved TOW. Physical recoil and weight shifts on launch are not simulated.

Target acquisition time, time of flight, impact accuracy and all actions by the gunner are automatically recorded. These measures are displayed on the screen of the notebook computer providing the instructor with immediate, objective feedback to monitor student performance. At the end of each engagement, the target scene visible at the time of the missile's impact can be recalled; a marker displays the location of impact. Following the engagement, plots of the gunner's point-of-aim and the flight of the missile in azimuth and elevation can also be displayed on the monitors. Point-of-aim and the position of the missile relative to the target are plotted in mils (or metres) as a function of range. Hardcopy printout is an option, not yet implemented. The instructor and other students can observe the gunner's actions on the instructor's monitor, a high resolution colour display. Other instructional features include the ability to simulate misfires and wire breaks, to freeze action and to restart or randomly access new engagement scenarios. Interactive training among the commander, gunner and loader of a TOW detachment is possible. Commanders can issue fire orders based on the information seen on the instructor's monitor. Because more than one missile can be fired and some engagements provide more than one target, gunner, loader and commander can interact during an engagement.

Detailed discussion of the various aspects of TVIGS, including technical, perceptual and pedagogical characteristics, is provided in the following sections.

Visual System

A proprietary video processor (patent pending) used in conjunction with commercial video products and a microcomputer system provides real-time interaction with video imagery. The source of the video imagery is non-specific. Composite colour signals from a radio frequency tuner for the reception of commercial television broadcasts, a videocassette machine, a television camera, or a videodisc player can all be used. RGB and synchronization signals from a computer system are also acceptable. For the present application, the most practical source of video imagery is a videodisc containing prerecorded background scenes including targets.

Each side of a videodisc is capable of storing 54,000 colour television pictures, or frames. This translates to 30 minutes of action if used in a continuous play mode. The advantages of a videodisc-based system include high fidelity, low-cost and reliability. The imagery stored on the disc may come from various sources, for example, from film, slide, photograph, videotape, or computer. The videodisc is simply a cost-effective medium for the distribution of visual training materials. Videodisc scenarios derived from videotape or film have the advantage of containing realistic targets manoeuvring tactically on natural terrain.

The use of a videodisc system avoids many of the high costs currently associated with developing and maintaining computer generated imagery systems by curtailing the amount of mathematical modelling necessary. Consequently, the computing requirements are minimal, allowing the use of inexpensive, readily available microcomputers to handle real-time processing. Recurring costs are minimized too, no maintenance of the visual data base is required since the information is stored in a non-volatile format.

The videodisc player uses a laser to read the information encoded on the videodisc. The information is stored as a series of microscopic pits arranged in concentric rings, one ring for each video frame. The pits affect reflections of the laser beam off the disc's surface that are sensed by a photo-sensitive diode. Because there is no physical contact with the videodisc, recorded information can be repeatedly accessed without wear. The prototype TVIGS uses an industrial videodisc player (Pioneer LD-V1000) under computer control via an interface unit (Technovision TSI-101). For an introduction to videodisc technology and microcomputer applications see [3].

The analog output of the videodisc player is fed to the input of an NTSC colour decoder (Electrohome ECP-1000). Separate analog signals for the red, green and blue constituents of composite video then are transmitted to three video digitizers, one for each colour. The digital data are stored in high speed, serial access memory devices. Encoding and retrieval circuits permit a part of the original data to be reconstituted as an analog signal for an ordinary RGB monitor. In effect, each video frame is converted to a virtual image twice its normal height and width. One quarter of this virtual image is then selected for display by the application software. The portion selected is contingent on the aiming point of the gunner. In this way, the visual imagery displayed to the gunner through his sight is slaved to his point-of-aim.

This technological approach suits the application. A wide field-of-view is unnecessary for training a TOW gunner. His sights have a very limited field-of-view and his task, aligning the cross hairs and target, confine the area of visual interest. Therefore, only a limited degree of interaction with the visual world needs to be simulated. However, in order to achieve effective training of visual-motor skills it is important to minimize the temporal asynchrony (also known as transmission lag, transport delay, or phase shift) between control movements and their visual consequences. This issue has drawn attention in flight simulation because temporal asynchrony can disrupt performance. Visual-motor performance tends to degrade with increased delay [4]. Currently, the advice for flight simulators is that display lags should not exceed about 125 msec [5]. Because the TOW optical sight is coupled directly to the traversing unit, control movements made by the gunner normally change the scene immediately. This situation is more rigorous than that for flying where the fluid properties of the air and aircraft inertia introduce elasticity and lag in the temporal relationship between the control movements made by the pilot and what he sees outside the cockpit. For this reason a more stringent criterion for visual asynchrony is in order for an effective TOW simulation. The most stringent achievable in the context of commercial television standards is 1/30 Hz. TVIGS meets this criterion.

Visual effects such as fog, smoke and conversion of daylight scenes to simulated thermal scenes are accomplished by superposition of computer generated imagery and by translation of the digital data representing the source material. These features allow flexible use of prerecorded imagery. They extend the usefulness of the training materials by varying the target conditions and afford training otherwise difficult to achieve.

The results of the video processes described above are displayed on two high-resolution monitors, one for the instructor and the other for the gunner. The instructor's monitor is a Sony 12 inch PVM1271Q. An overlay attached directly to the screen of the monitor can be seen in Figure 1. It represents the graticule pattern that would be seen through C1 binoculars used by the commander of the TOW unit. The purpose of the graticule pattern is to facilitate visual judgements of target range. The usefulness of this feature has yet to be determined.

The TVIGS sight assembly is shown in Figure 2. It incorporates an 8-inch Sony KX-8200CD monitor fitted with an 11 cm diameter mask and cross hairs. The screen is viewed through an adjustable eyepiece containing a positive meniscus lens (Melles Griot catalogue no. 01LMP011) 50 mm in diameter with a 150 mm focal length. The eyepiece and screen are enclosed in a light-tight metal shield to exclude stray light and to optimize viewing conditions.

The optical design requires that the eye be kept as close as possible to the lens in order to minimize the effects of parallax between the graticule and the screen and of spherical aberrations. The latter are evident as image distance or deviation from the axis increase; from this point of view the system may be described as pupil forming. The lens places the optical image near infinity. This helps alleviate eye strain since the actual distance to the screen is only about 15 cm. Normally, the eye would have difficulty focusing objects this close for an extended period of time.

The instantaneous field-of-view of the TOW optical sight is about 6 degrees in diameter. With x13 power the optical image visible through the eyepiece subtends about 78 degrees at the eye. This is equivalent to a solid angle of about 1.45 steradians. The instantaneous field-of-view of the TOW night sight is rectangular with a ratio of height to width approximately 1/2. Two power settings are possible, x4 and x12. On x12 the field-of-view is about 1.1 by 2.2 degrees. In comparison, the apparent field-of-view of the TVIGS is only 40 degrees in diameter or .38 steradians. This design choice was made for the following reasons:

1. The principal goals of the TVIGS are to assist the acquisition of visual-

motor skill, procedural knowledge, and the making of tactical decisions. Learning to detect the presence of targets by surveying of the visual field and learning to recognize and identify distant targets were not the predominant aims of the design.

2. In order to maximize the gaming area about a target, targets will generally appear near the centre of the visible scene.
3. Because the task of the gunner is to maintain his cross hairs on the target, the target should also remain near the centre of the screen. The amount of deviation will depend, of course, on the skill of the trainee, but tracking error is likely to be relatively small when compared to the size of the through-sight scene.
4. The gunner's eye should continuously track the target. Visual acuity diminishes rapidly with distance from the fovea, that portion of the retina upon which visual targets are focused. For levels of luminance sufficient to sustain photopic (daylight) vision, relative acuity drops to one-tenth at ten degrees from the centre of the fovea, for example for luminance levels of 73 foot lamberts. A target 20 degrees from the fovea would have to be about 20 times larger than a target of similar shape, colour, size and contrast focused at the centre of the fovea to be equally detectable. Sample readings through the TVIGS sight indicate luminance levels of approximately 23 foot lamberts. This means that visual acuity will decay even more rapidly than the rate indicated above. It should be noted that 23 foot lamberts exceeds by an order of magnitude the maximum luminance values of a typical flight simulator, but that it is considerably less than daylight.[1]

The net result of these considerations is that much of the periphery of the normal target search area will be overlooked and that it is unnecessary, therefore, to simulate the full apparent field-of-view of the TOW sight. The remaining components of the sight assembly include a protective shield for the monitor, a mounting bracket, adapter plate and locking clamp. The sight assembly can easily and quickly be secured to the traversing unit by clamping it in place of the actual sight.

Although the design of the visual system described above is relatively simple and inexpensive the images lack definition because they are television-based. Only low spatial frequency information is preserved. Previous research at DCIEM, however, has demonstrated that the visual fidelity of commercial television is sufficient for gunnery training. The validity of the approach has been established by field trials of a part-task gunnery trainer for the Leopard C1 tank that demonstrated positive transfer of training [7]. Physical characteristics of the visual display can affect image quality, but they do not necessarily affect its usefulness for training. Furthermore, operational conditions also often degrade visual clarity; obscuration of the target by dust, smoke, heat shimmer, fog and reflected light are common.

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[1] See Van Cott and Kincade [6] for substantiation of the figures given above and for elaboration of the human factors issues related to visual acuity.

The colour, luminance and contrast of the visual display are characteristic of commercial television However, the digital representation of the analog video signal for each primary colour is only 4 bits. The effect of this quantization is to limit and step, or stratify, the colour range. In total, 4096 colours are possible. Quantization error also introduces some instability in the image This latter effect is perceptible only when the videoframe is frozen for a static shot.

Television screens cannot duplicate the luminance or contrasts of daylight. Of concern is the distracting effect of the flight motor and TOW beacon, which are very bright Gunners are known to track the missile rather than the target thereby increasing the probability of missing the target. One explanation for this error is a phenomenon known as "visual capture" Bright lights attract attention and visually distract the gunner from his task. Since the brightness of a television screen is very limited, two other means of distracting the TOW gunner have been employed to teach him to ignore the missile. The visual angle of the simulated beacon is larger than normal and it flashes at about 4 Hz. These characteristics have attention-getting value [6] and are used to simulate the distracting effect of the bright missile

Training Materials

Video images generated by computer (RGB) can also be processed. These images may be entirely computer generated or they may be digitized video scenes. Videodisc training materials for possible use with the TVIGS are presently made by Perceptronics Inc (Woodland Hills, California), General Electric Company (Daytona Beach, Florida), and Educational Computing Corporation (Orlando, Florida) Soon Simtech Advanced Training and Simulation Systems Ltd. (Tel-Aviv, Israel) will also have useable targetry

Audio System

Digital data are used to simulate the audio effects of a missile launch and impact These may be delivered through commercial high-fidelity headphones or an optional speaker system. A headphone jack and volume control are located on the launcher interface unit to facilitate access by the trainee The audio system does not reproduce the overpressures typical of a TOW launch because these are dangerous to hearing. Repeated exposure, especially within a short period of time, would cause physiological damage to the ear TVIGS allows unlimited training For this reason, the sounds are limited to 125 dB Prerecorded sounds also can be stored on the stereo sound tracks of a videodisc and mixed with those described above

Computer System

The microcomputer system controls and monitors all practice on the trainer. The application software is presently stored on a Winchester disc. It is executed using an Intel iSBC 86/12A compatible single board microcomputer (Matrox MBC-86/12A) with a 8087 math processor. Internal RAM is 640K bytes. A Mitsubishi Model M4851 disk drive for 5 1/4" diskettes is available for long term data storage. A Z80 single board computer is also used to store and execute audio effects, operating in parallel with the 8086 microcomputer. A Multibus is used as a backplane. Most of the applications software is written in C, which was chosen to minimize assembly language requirements and to maximize portability. The operating system is CP/M-86.

Digital data specifying target location, size, and range are kept on a floppy diskette, one for each videodisc. These data are used by the applications software to determine tracking accuracy and the correspondence between the missile's flight path and the centre of the target(s). The values for these measures are subjective, based on perception, not instrumentation. The most subjective is target range. Objective physical measures of range, for example, are unnecessary and superfluous because psychophysical and perceptual factors influence the judgement of distance. The visual system transforms image content. It is unrealistic to expect a visual simulation system to match the performance of the human eye. Even the most expensive visual displays cannot match the dynamic range and sensitivity of the human eye. As a result the fidelity of any visual display is limited and it is necessary to consider the effects this will have on perception. High perceptual fidelity is a prime goal for simulation. The aim is to expose the trainee to situations that would encourage him to respond in the same way as he would to the real thing. In this way, transfer-of-training is accomplished.

Researchers and artists have identified a large number of perceptual cues for monocular depth perception, often called pictorial cues. The visual angle subtended by an object of known size, its interposition among other objects, its proximity to the horizon, its colour, apparent contrast, shading, brightness, clarity, and relative motion are some of the cues unconsciously used by static observers to estimate the distance of a static object. Linear perspective and texture gradients are also used. Some of the associations among these cues are maintained by the simulator's visual system, others are not. Hence, subjective estimates of the target range are sufficient. These estimates are not hard and fast since individuals differ considerably in accuracy and reliability when judging target distance. There is no strong need to be more objective about target range since its judgement is not a training requirement. The TOW sighting system provides only cross hairs for alignment on the target; judgements of range based on the known size of a target are difficult without graduations to facilitate range estimation.

Instructional Facilities

As mentioned previously, the instructor's station consists of a video monitor and a notebook computer. The notebook computer (NEC PCS201A) is an off-the shelf microcomputer. It is self-contained, low-cost and robust. Expansion options offer flexibility in its applications. Key advantages of the system include ease of operation, useful functions, and access to commercial software. The latter is not necessary for the TOW simulation, but does extend the general usefulness of the device. A significant advantage of this model for experimental use is that commercial software for personnel testing is available. Standardized psychometric tests have been implemented on this device to test reaction time, pattern recognition, decision making and other abilities. Additional advantages of this system and details about these tests are documented elsewhere [8 & 9].

The notebook computer is used as a terminal for sending commands to the applications software and for receiving feedback about the engagement. Many of the commands are menu driven. They prompt the instructor to choose a training engagement and to specify the visibility conditions (i.e., day, fog or thermal). Single key strokes allow the instructor to start, freeze, continue or abort a training engagement at any time. The instructor may inject a wire break at any time during the course of the engagement. He can determine in advance a misfire of the launch or flight motors. All actions by the gunner during the engagement are automatically recorded. A chronological summary is displayed on the liquid crystal display of the notebook computer. For example, the times at which the gunner aims the missile and presses the trigger, the time and the point of impact, the time the bridge clamp is released and the time a new missile present signal is registered are all logged in real-time. The instructor is able to monitor all actions. Following the engagement he may also select additional feedback about the gunner's actions. Separate records for each missile are maintained. Its point of impact can be displayed visually on the television screen. Plots of gunner aiming error and the flight path of the missile can be displayed. Key events, such as the time of a wire break, or motor failure, are logged. An audible tone is sounded if the gunner's point-of-aim and the missile beacon depart unacceptably.

DISCUSSION

The design of the TVIGS prototype attempts to mesh training requirements, video and microcomputer technologies, human factors and learning principles in a cost-effective manner. Lessons learned from previous research and development efforts involving a videodisc-based, part-task trainer for the Leopard C1 tank are applied to the design of the TVIGS prototype The key component of the TVIGS is its visual system It can accept realistic video imagery from a variety of sources for gunnery training The design of the visual system attempts to maximize visual fidelity and versatility. Full use is made of high-resolution television screens. The use of prerecorded video scenes is maximized by providing means for manipulating the imagery

No single component of the TVIGS is particularly expensive Most items are available in quantity off-the-shelf, are second-sourced, and are substitutable. Modularity helps reduce initial purchase price and maintenance Even if few production units are purchased, economies of scale are obtained since most of the components are manufactured for the public market A major cost for this type of trainer is the production of video training materials Because the TVIGS prototype will accept imagery produced for other video-based systems, and because the requirements for the source material are common to videodisc-based trainers for other direct fire weapons such as the Leopard C1 tank, cost savings in this area are possible

The system described here is amenable to other military training applications that rely on visual information to guide learned behaviour The video interactive gunnery simulator concept provides an attractive alternative to expensive computer generated imagery systems It is limited in its application, however, to operational situations having a confined area of visual interest and where a minimal amount of additional dynamic visual information needs to supplement background scenes Nevertheless, there is a fairly wide range of military tasks in need of training that meet these requirements Simulators for direct fire weapons seem particularly appropriate for the approach, especially since it is often very expensive to train personnel using live rounds

Training Effectiveness

In concept and implementation the TVIGS adheres to established principles of simulator design Perceptual fidelity, immediate feedback and diagnostic instruction are some of its important design goals Useless features have been avoided. Automated performance appraisal (i e , computer scoring) for example has not been implemented because of its doubtful value [10 & 11]

The TVIGS should provide training on important gunnery skills beyond the repertoire of the M70 trainers. Students may practice engaging realistic targets, some of which are camouflaged or evasive. At the present time, neither garrison training, nor live fire training, provides targets of this type. Since the simulator does not require a real target vehicle or expensive operational components, it will be much more inexpensive to operate and maintain. It should also promote student interest by allowing all class members to observe the engagement and by providing immediate feedback. The arcade-like features are stimulating, as is the wide variety of targets. An important instructional assest is that the instructor can monitor all the student's actions and is able to present a wide range of target scenarios. Potentially, there are no limits to the number and variety of targets he may use. Also, it is possible for him to exercise a degree of control over training not currently possible by capitalizing on the fact that the simulator is programmable. The instructor can insert a misfire or wire break at will; problems that now occur on chance occasions. Portability and ease of set up also mean that militia and reserve units can have access to the device. The system requires only a small amount of space. Some interactive team training is possible, members of a TOW detachment can be trained simultaneously. Commanders can issue fire orders based by visually sighting targets on the instructor's monitor. Since more than one missile can be fired during a single engagement, the loader also could participate in the engagement.

Although the TVIGS prototype has high content and face validity, no tests have yet confirmed transfer-of-training. The issue is problematic because few missiles are available to assess transfer. Conventional empirical methods for determining the training effectiveness of a simulator require criterion measures of trainee performance on the operational equipment. Because TOW live firing is limited, user trials will be conducted and training effectiveness inferred on the basis of reverse transfer-of-training and performance prediction. Discussion of these methods and the relevance of the information they yield are provided elsewhere [12 & 13].

Summary

The following list of features summarizes the principal design goals for the TVIGS prototype

- Student motivation
- Perceptual fidelity
- Diversified training
- Immediate feedback
- Objective performance measurement
- Saturation training
- Off-the-shelf hardware
- Real-time response
- Low-cost
- Simplicity
- Easy maintenance
- Reliability
- Portability and easy set-up
- Classroom training
- Flexibility
- Modularity of hardware and software
- Training media compatibility
- State-of-the-art technology
- Expandability and upward compatibility
- Crew training

ACKNOWLEDGEMENTS

Several people in the Simulation and Training Group at DCIEM contributed to the design and fabrication of the TVIGS prototype. Mr Stephen King was responsible for electronics design and hardware integration. In addition, he provided source code for device drivers and audio effects. Dr Dave Sweeney consulted on the optical system and implemented in software the aerodynamic model for the TOW. He also provided a mathematical technique for generating fog. Mr Ralf Kuehnel was the software specialist responsible for integrating all source code and for generating, implementing and testing the bulk of the applications software.

Sound pressure measures were taken by Mr Brian Crabtree, advice about sound level exposure was gained from Mr Stan Forshaw. Mr Bruce Ferguson provided early advice on hardware techniques. Illustrative drawings were provided by Mr V. Praestegaard. Their help is appreciated.

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