DEVELOPING INTELLIGENT INFRARED TARGETS FOR TESTING AND TRAINING (IRT^3)

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Abstract

This paper will describe the developmental steps of a Live Fire Testing and Training Initiative project to develop intelligent, interactive infrared (IR) targets for use in both training and testing. The University of Central Florida (UCF) team will develop an IR projection capability suitable for providing live-fire targets for testing and training with IR systems in the 8-12 micron band. The system will use a Computer Generated Forces (CGF) system to control the IR projector imagery to provide intelligent, shoot-back capable, IR targets projected onto a fountain of water.

Current IR Target systems are unsatisfactory. Conventional approaches use IR targets physically heated with heating strips that are constantly being "blown away" when used in live fire. In addition heating strips have slow response time and cannot provide fast changing and moving imagery. Scanning laser projectors are not suitable since their interaction with the scanning mirrors in Forward Looking Infra Red (FLIR) sensors produces the appearance of a cloud of butterflies.

The unique developmental approach detailed in this paper is based on the Texas Instruments (TI) video projector Digital Light Processor (DLP) technology. The project is designed to produce the full range of military targets on unique reusable and renewable water-based projection screens.

Biographical Sketch:

Dan Mullally, a retired Marine Infantry officer, has been a Research Scientist at the UCF, Institute for Simulation and Training (IST), since 1982. His responsibilities have included organizing and chairing seven annual 3-day international conferences on CGF and Behavioral Representation. He continues to support and organize those DoD sponsored conferences. He served as the Co-PI for the Advanced Amphibious Assault Vehicle project to "Determine the Feasibility of using Virtual Simulation for Test and Evaluation". He is currently involved in the development of the Advanced Tactical Engagement Simulation (ATES) system Science and Technology Objective (STO) System for STRICOM, the Concept Formulation Plan development for the Objective Individual Combat Weapon (OICW) for U. S. Army PM Small Arms and STRICOM, and the IRT3 project for the USMC. He has an M.A. in Human Resources Management from Pepperdine University and a B.S. in Business Administration from Western Carolina University.

Dr. Thomas L. Clarke is a Senior Scientist at the Institute for Simulation and Training at UCF. He has more than 15 years research experience involving propagation modeling, digital processing of acoustic signals, statistical analysis, and numerical modeling. He has two patents. Dr. Clarke has published extensively in professional journals and is affiliated with the Institute of Electrical and Electronics Engineers and the Audio Engineering Society. He received his Ph.D. and M.S. in Applied Mathematics and a B.S. in Mathematics.

Dr. Glenn D. Boreman is a professor of Optics at UCF, Center for Research & Education in Optics and Lasers (CREOL). He is the author of over 70 research papers related to IR Systems and Technology.

INTRODUCTION

US Forces have "Owned the Night" since Forward Looking Infrared (FLIR) devices were introduced for use on vehicles and aircraft and Night Vision Goggles (NVGs) were issued to Individual Combatants (ICs). This improved combat capability provides a decisive advantage to the US Forces engaged in combat during the day, at night and under periods of reduced visibility. The ability to train with live infrared targets (See Figure 1.) has been severely limited due to the lack of inexpensive live, reactive, and realistic targets for training and testing. This has reduced the training capabilities and the combat readiness of US Forces.

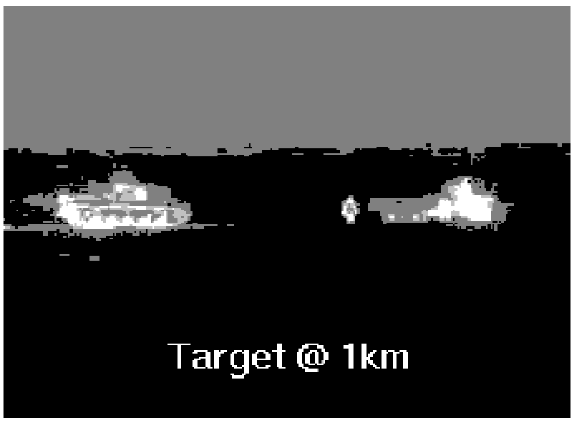

Figure 1. FLIR Imagery of Military Targets

Background and Objectives

Training in the use of FLIR (forward looking infrared) and other IR technology requires live fire targets that closely mimic the appearance of real targets in the IR. Approaches have been developed involving heated surfaces, but these are more costly than is desirable. To be acceptable IR targets need to be capable of matching the realism of the combat system being projected. For a vehicle target this means that the image is a close match in size, shape, and IR radiance. For a man-sized Individual Combatant (IC) target the size, stance, and IR radiance must depict a realistic image of the IC and his weapon. All IR projected targets should be capable of projecting a thermal model that incorporates the radiance of the target adjusted for the temperature-dependent emitted radiance; the skyshine, earthshine, solar, and secondary reflected radiance.

Existing ground live-fire ranges are normally arranged to provide a varied target array to military forces undergoing initial or sustainment training. Test ranges are also designed and laid out to capture accurate data for test and evaluation.

Both types of ranges have targets located at various distances from carefully surveyed firing points. The targets may be obsolete vehicles known as "hulks". Their blackened appearance, their missing parts, or the large number of holes in their sides usually characterize these hulks. The area around these hulks is also blackened with little or no remaining foliage.

Personnel targets on these ranges are usually constructed from arrays of standardized "E" type silhouette targets attached to wooden stakes. The outline of the torso (the thoracic region of a standard male) is presented in a column, "Vee", wedge, line or some other formation representative of small unit tactical maneuvering. These targets may be instrumented to detect hits by employing acoustic sensors, strain gauges, or hit sensitive surfaces on the individual targets. The targets may be fixed in place incapable of movement or they may be mechanically raised and lowered by target carriers. The target mechanisms may be computer or human operator controlled.

Most target arrays are visibly distinguishable by the "beaten zone" of naked stripped vegetation and raw earth surrounding them caused by extended use in live firing exercises. The target arrays are placed in position to be "seen" and "fired at", not to depict a maneuvering force. These targets provide a cheap, non-responsive target for firing practice. While they may assist in determining a weapon system's zero they provide little "transfer of training value" to demonstrating, teaching, or practicing tactical decision-making skills.

Developmental Approach

The IRT3 developmental approach will be discussed. The first section deals with concepts for renewable and reusable projection screens and how they can be integrated with the test range. The second section discusses in detail how the DLP technology will be utilized in an infrared projector. Finally scene generation and interface to other simulator systems will be discussed in a third section. This order of presentation and discussion also closely parallels the chronological sequence of tasks to be performed.

1. IR Targets Projection Screens

The first step in the IRT3 Project was a low-cost Proof-of-Principle demonstration. Figure 2. is a composite photograph showing the initial lab test environment used to project an IR source onto water.

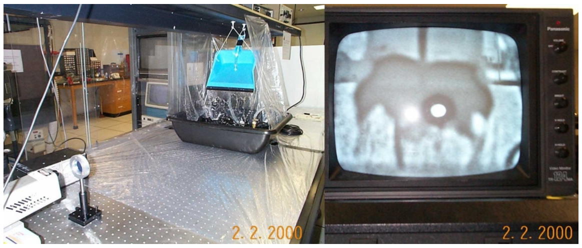

Figure 2. Experimental Lab IR Image Projected on Water

On the left of the composite picture shown in Figure 2. is an eye safe barrier consisting of clear plastic sheeting which was constructed to enclose the experiment. A small water pump was used to lift the water from the black plastic mixing tray and spray water down onto a blue plastic dustpan. The dustpan was selected to disperse the water into a solid sheet and provide a flat waterfall with little or no spray. An IR laser source was focused on the falling water. The right half of the composite picture shows the video image of the white circular spot of projected IR light picked up by an IR camera operating in the 8-12 micron range.

Once the initial Proof-of-Principle demonstration was successfully completed concept design proceeded to evolve.

Figure 3. Artist's Concept of appearance of projected targets on a training range

An artist's conception of how the projected targets would appear to a user of an IRT3 equipped test/training range is shown in Figure 3.

The targets would be projected using UCF team developed infrared projectors onto water screens that would be unobtrusive in the absence of projector energy. Under computer control the projected images could appear and disappear realistically, simulating actual targets maneuvering from covered positions into firing positions on the terrain. The projection machinery would be hidden and protected behind earthen or concrete berms so that only the image projected on the water screens would be subject to being seen and hit by live fire.

State-of-the-art acoustic sensors or Doppler radar technologies can be used to determine where the fired round crosses the plane of the screen for scoring purposes. The acoustic technology is currently in use at several U. S. Army ranges. Doppler radar technology is currently planned for research and development by the U. S. Army as it offers the capability to accurately detect and score sub-sonic munitions.

Once the fired round is sensed the CGF system controlling the behavior of the projected image would react according to pre-set rules or to any selectable behaviors evoked by the range control officer.

A water-based screen for IR projection appears quite feasible, with design issues to be determined of the distribution of droplet sizes, and the spatial density of the droplet dispersion. Water would be an ideal projection screen for live fire training exercises as it is inherently renewable and offers a relatively low or maintenance free medium when compared to plywood, cloth, or paper targets currently in use.

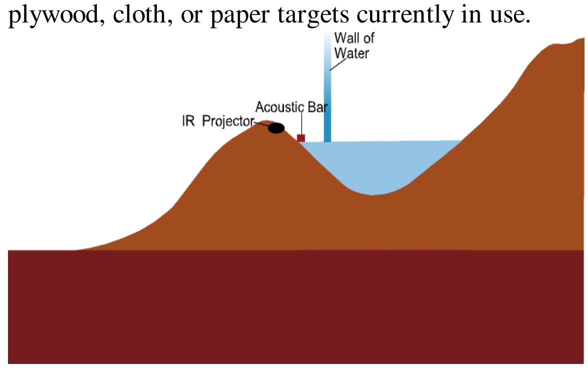

Figure 4. Relationship of components of IRT3 on test range

Central to the IRT3 project is the concept of providing an integrated system of live-fire target arrays that are realistic. This means that the targets behave in a manner to be expected of an intelligent, aggressive opposing force capable of decisive action given an opportunity to engage friendly forces. Realistic opposing forces need to be capable of unpredictable behavior using the terrain to fire and maneuver to their advantage. Hulks do not provide an intelligent, aggressive enemy force.

The optimum live-fire target array would allow for free maneuver over any portion of a live-fire range. This obviously will never happen due to the over-riding safety requirement when firing live rounds. While reduced range ammunition fulfills some of this requirement it literally "falls short" in meeting the requirement to "train as we fight". Only by using full-range ammo and live, intelligent, and responsive targets can we meet that need.

Target arrays should be made more realistic, more responsive, more intelligent, and more maneuverable. That is a design goal of the IRT3 project.

Designing the optimum range to make full use of a projected IR image becomes a challenge to place as many arrays as possible to cover to the fullest extent the fire and maneuver of an opposing force on the selected live-fire range terrain. Water filled ponds or even canals may be a design option. (See Figure 5)

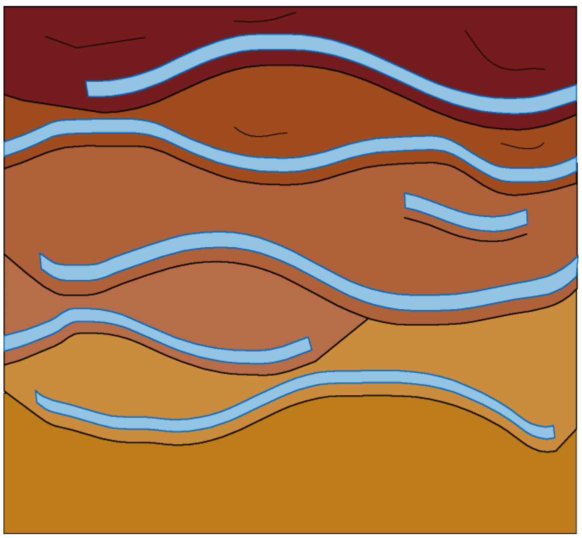

Figure 5. Water canals allow optimum IR Targets placement

2. Infrared Projection Development

The basic design for an IR projector, based on DLP video projectors, has been proven. This project will adapt this technology to the live-fire test and training arena.

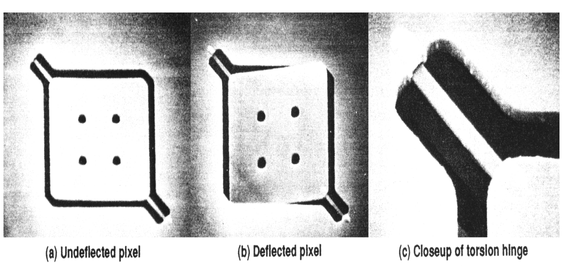

Figure 6. Photomicrograph of individual TI DLP pixel

The TI DLP is a unique spatial light modulator technology developed over the last 15 years, primarily for HDTV and cinematic-projector markets. A DLP chip consists of a 600 by 800 array of individually addressable mirrors as shown in Figure 6. In response to input video signal, the individual mirrors tilt, impressing information onto a reflected beam of radiation. Figure 7 shows how the individual mirrors are closely packed into an array of imaging pixels.

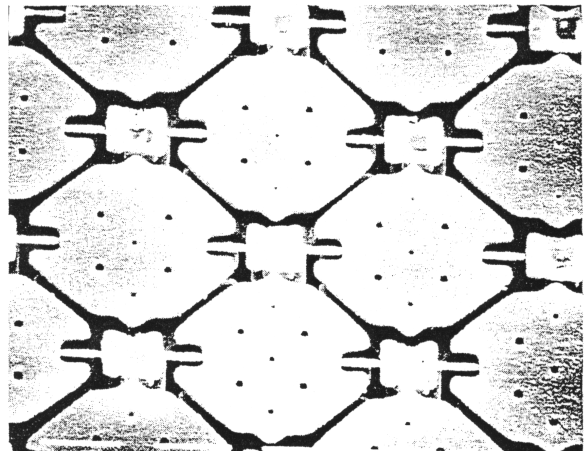

Figure 7. DLP pixels form a close packed array

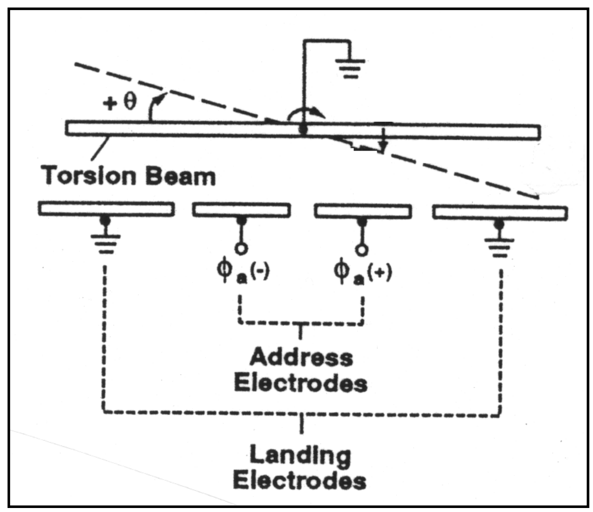

Figure 8. DLP pixel mirrors tilt under influence of electrostatic forces.

Figure 8 illustrates how the pixel mirrors are tilted via electrostatic forces generated by addressing voltages applied to the chip substrate below the pixel mirrors.

The IR Scene Projector (IRSP) is basically an infrared movie projector. IRSPs can be based on either raster scanned lasers or digital-light-processor-based (DLP) systems. In each case the idea is to create a dynamic IR scene that simulates a given target and background condition.

Whereas laser scanners require moving parts, DLP technologies are typically solid-state based, and are compact and rugged. DLP based IRSPs can use either laser of thermal infrared emitters, such as incandescent or LED sources.

The IRSP system allows both training and exercising of IR sensor & system functions (detection, tracking, acquisition, etc) without the need to have real hardware (tanks, planes, or missiles) actually in use. This saves money and also allows considerable test flexibility, e.g., replay of test cases searching for infrequent failure modes.

The result will be a large improvement in the realism of IR targets suitable for live-fire training and testing. The use of projection technology will permit the isolation and protection of the expensive projector, only exposing a relatively inexpensive projection media to destructive fire. The projection media will be less costly than current targets so the result will be improved realism and cost savings.

A DLP-based IR projector is capable of high-resolution projection of IR scenes onto a water target screen. The array format of the DLP avoids temporal aliasing and flicker problems associated with scanned-laser-beam projectors. The modulation of the DLP is accomplished via pulse width modulation (PWM). The mirrors are tilted rapidly (microsecond scale tilt times) across the entire pixel array. The amount of time that the each pixel is tilted is varied to produce a continuously variable range of pixel intensities.

R&D issues that arise because DLP chips are optimized for visible radiation include:

- Pixels are smaller than ideal from a diffraction point of view.
- Projected resolution will probably be 256 squared.
- Advantage is that they are commercially available in the <$10 k range.
- Modifications to the chip window are necessary, the one supplied is IR opaque, therefore a custom IR-optical train required.

None of these issues are viewed as insurmountable; they will be addressed during the first year of the project.

A CO2-laser-based IR scene projector using the DLP will be developed in support of this project. This projector will have better flux-transfer compared to use of a thermal source, particularly for large-area outdoor projections. To accomplish this IR radiation from the laser is incident on the DLP as a parallel beam as shown in Figure 9.

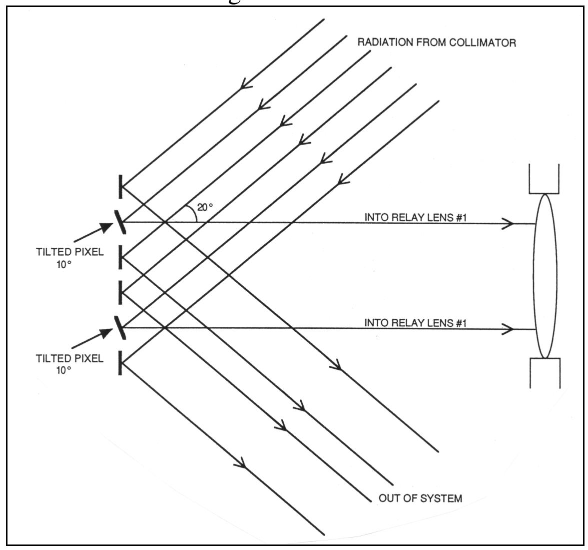

Figure 9. Drawing showing how tilted pixels direct IR into projection lens.

Tilted pixels direct radiation into the aperture of the projector. Non-tilted pixels direct radiation to miss the projector aperture. The imaging lens then provides appropriate magnification of the illuminated DLP onto the water screen as shown in Figure 10.

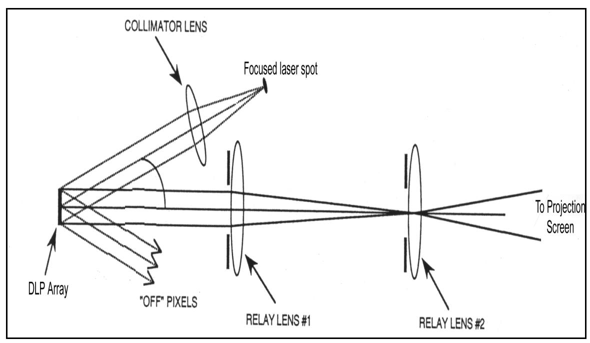

Figure 10. Relay lenses send IR image to screen

The optics train required for implementation of darkfield illumination is straightforward, but produces binary illumination at image plane (either off or on). Using pulse-width modulation, DLP-based projectors successfully generate gray-level imagery. Within a single frame time of the sensor system, any given DLP pixel is tilted for a fraction of the frame time, which corresponds to the desired gray level.

The UCF Team developed a prototype IR scene projector in 1993 using this technology, for hardware-in-the-loop (HWIL) testing of IR seeker systems. Demonstration was done at TI's Central

Research Lab in Dallas. Ultimately, resistive array technology (a matrix of thermal emitters) was chosen as the configuration of choice for HWIL applications. The flux transfer from the thermal emitters was adequate to support HWIL, where the energy is projected directly into the entrance aperture of the unit under test. However, DLP/laser-based projectors will be the technology of choice for outdoor gunner-training applications because they offer:

- higher flux levels at the screen (better than thermal arrays)
- no flicker or aliasing problems (better than scanned IR lasers)

Given IR projection technology, suitable images must be generated for training and test in the IR wavebands. CGF will actively control the targets and interact with the live combatants on a live fire range. This concept additionally would allow for the employment of virtual environment After Action Review (AAR) capability to datalog, replay, and effectively critique the actions of all of the networked live and virtual entities engaged in the live fire exercise. This network's instrumentation would be designed to automate the capture of the data necessary to provide Verification, Validation, and Accreditation (VV&A) of IR system training and/or testing.

3. Intelligent Infrared Image Generation

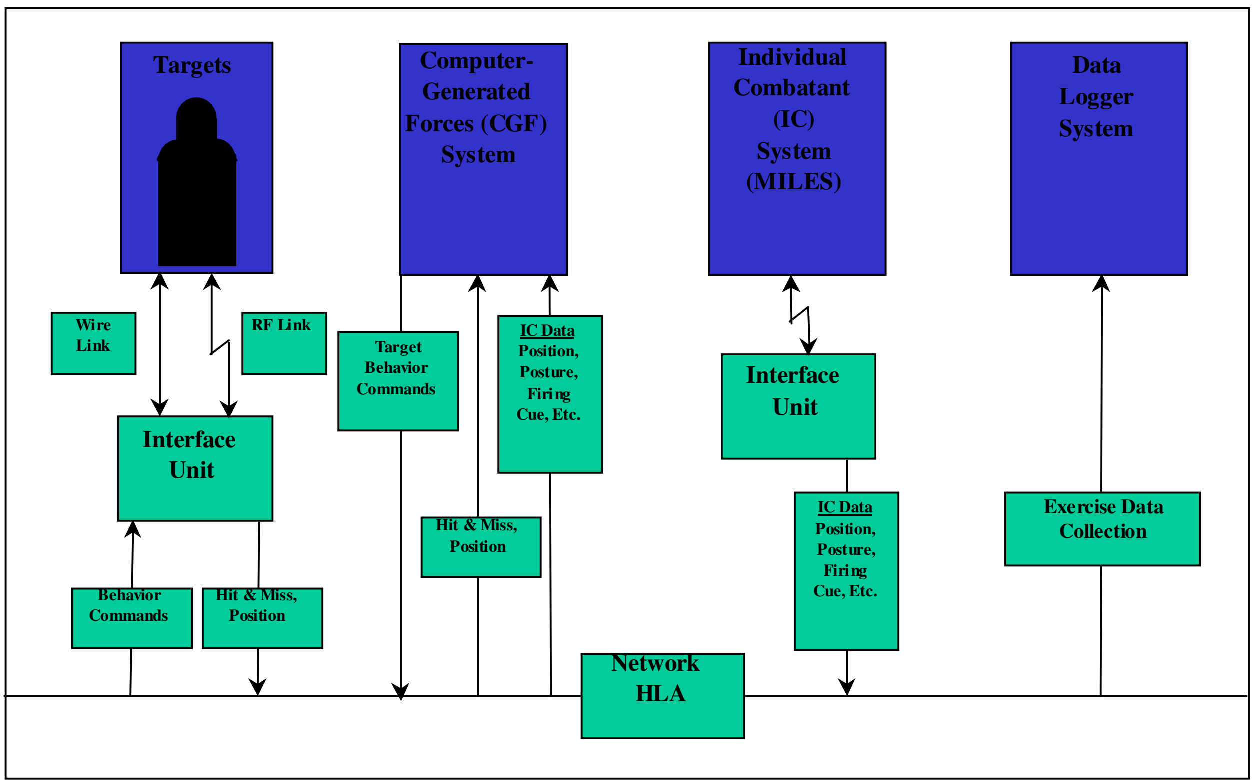

Figure 11. Software components needed to drive IRT3 projector on the live-fire range

The basis for our approach is the distributed simulation (HLA protocol) representation of battlefield entities and events. By instrumenting the live ICs and targets on a live fire range, and making the targets controllable through the use of computer generated imagery feeding the IRSP, entities in the live-fire exercise can be linked together via distributed simulation almost as flexibly as if they were in a virtual environment.

Figure 11 shows the components of the proposed interactive live fire range. The instrumented live ICs and the targets together define the live IC entities in the HLA environment. The targets in effect form a display device that shows the live ICs the state of the CCHs (Computer Controlled Hostiles) generated by the CGF. Targets placed at many sites on the range are activated in sequence to show a CCH advancing toward the live IC. Raw data from the live ICs and the targets are used to generate the firing and detonation events. The CCHs respond to the state of the live ICs and broadcast their own state. The logger captures all HLA packets for later analysis and replay in a virtual environment. A stealth display can show the live fire exercise in progress or replay the exercise from logged data.

An HLA-compatible CGF system has been developed to control the actions of CCHs in a virtual urban environment. This CGF system originally supported the USMC Team Target Engagement System (TTES). The TTES project name was changed to SUTT - "Small Unit Tactical Trainer". SUTT currently uses a computer generated virtual world modeled on the real environment of the Combat Village located at MCB, Quantico, VA. The SUTT CCHs detect the live ICs, seek cover, change posture, and return fire. This CGF system could be adapted to control entities represented by live fire targets. The CCH targets could thus be given "missions" by an instructor, perform coordinated actions, be suppressed by live IC fire, exhibit symptoms of fatigue, and choose to advance or withdraw. The CCHs could perform the 3-5 second forward rushing movement by raising and lowering a sequence of targets in different locations which correspond to each sequential firing position. Several components of the SUTT CCH system would be extended as described below.

The Live IC Interface Unit (see Figure 12) is a notional piece of software that connects the instrumented live IC to the HLA environment. Location and weapon fire information from systems such as augmented MILES-2000 would be converted to packets and broadcast. Impact timing data (generated by the Target Interface Unit) would be combined with the weapon fire information to produce HLA Detonation packets. Finally, hits on the live ICs reported by the CGF system would cause the MILES-2000 equipment to signal a hit to the live IC. This discussion is meant to give a brief idea of the software issues that will be addressed in adapting CGF technology to IRSG. Scene generation for the IRT3 will be accomplished by adapting existing stealth displays (a simulator which visualizes only) to the task of driving the IR projector. This approach will minimize the cost and maximize the probability of project success.

The stealth display requires a terrain database to show the exercise. A human can seek cover from a direct fire weapon in as little as a 0.3 m depression in the ground such as in a one foot deep ditch, or behind a rock, or a log. Therefore, a high definition terrain database (TDB) with 1m +/- 1/3m definition in elevation is required. Two possibilities right now are the live fire range training sites at Ft. Benning, GA., or the Range 400 site at the Marine Corps Air Ground Combat Center (MCAGCC), Twenty-nine Palms, CA. These two are mentioned primarily as examples of what is available. It may develop that the best approach is to specially model high-resolution insets for extant databases since the range of motion of the IRT3 projected infrared target is small.

The CGF system described above would require modification to reflect the limitations in movement of

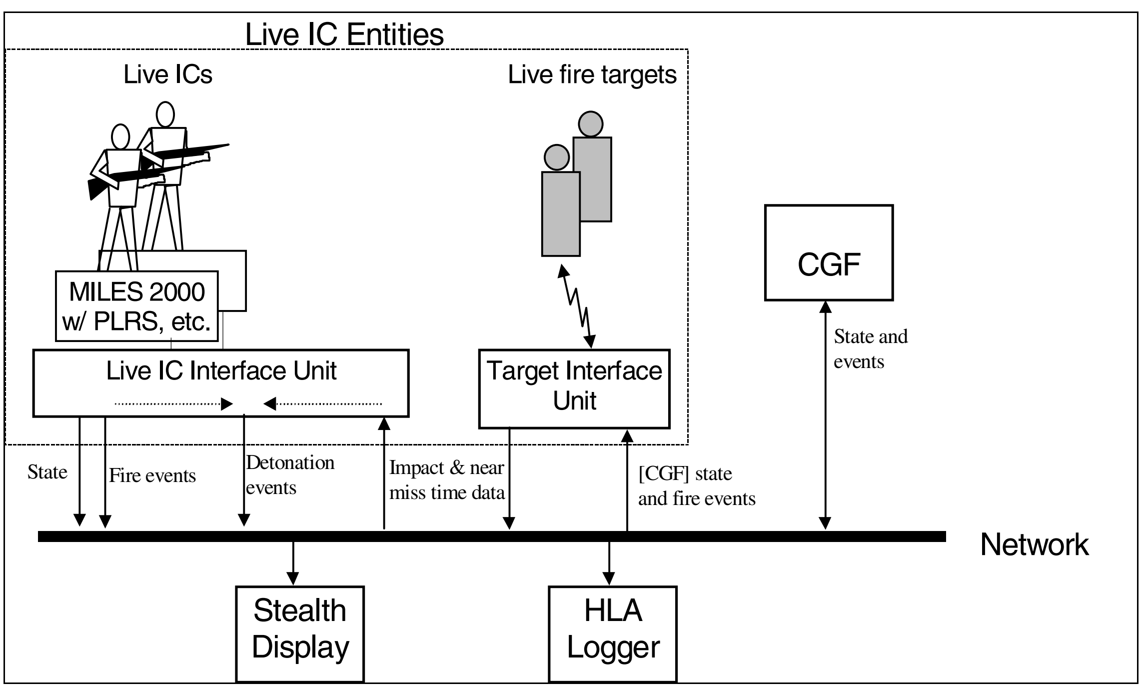

Figure 12. Interactive Live Fire Range using CGF network control.

the live fire targets. The CCHs should not be constrained to the discrete locations of the targets. If the CGF system contains a terrain database representing the live fire range so that CCHs can determine line-of-sight and report a correct location (elevation), the disappearance of the target behind terrain as it moves from the physical location of the projection screen can be simulated. This latter aspect would be tuned experimentally to attempt to provide the live ICs with a realistic target exposure time given the movement speed of the CCH.

The simulated targets could be augmented to simulate the firing of a weapon with a propane gas-driven or similar firing simulator. This would give the appropriate visual (FLASH or SMOKE) and aural (BANG) signature to the live IC. If the brightness of the IR projector is sufficient it could realistically portray firing or impact events. Burning and destroyed vehicle targets could be accurately shown as battlefield casualties, not requiring additional action.

SUMMARY

The successful Proof-of-Principle demonstration of IR projection onto water allows for the continued development of the IRT3 project. The next sequential steps in the IRT3 project call for the continued development of the IRSP, the development of a full-scale demonstration target system and the application of CGF control to the targets and the IRSP.