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PROTOTYPE DEVELOPMENT OF LOW-COST, AUGMENTED REALITY TRAINER FOR CREW SERVICE WEAPONS

by

Nathan Conger

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Thesis Co-Advisors: Mathias Kolsch
Joseph Sullivan

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A significant emerging threat to coalition forces in littoral regions is from small craft such as jet skis, fast patrol boats, and speedboats. These craft, when armed, are categorized as Fast Inshore Attack Craft (FIAC), and their arsenal can contain an array of weapons to include suicide bombs, crew-served weapons, anti-tank or ship missiles, and torpedoes. While these craft often have crude weapon technologies, they use an asymmetric tactic of large numbers of small, cheap, poorly armed and armored units to overwhelm coalition defenses.

Training on crew-served weapons on coalition ships has not advanced to meet this new threat. The current training methods do not satisfactorily train the following skills: Rules of engagement (ROE), marksmanship against highly maneuverable targets, threat prioritization, target designation, field of fire coordination, coordinated arms effects, or watch station to CIC communications.

The creation of a prototype Augmented Reality Virtual At Sea Trainer (AR-VAST) shows that emerging augmented reality technologies can overcome limitations of traditional training methods. A fully developed AR-VAST system would be a deployable technology solution that uses in-place weapon systems as trainers in real-world environments with simulated enemy targets. While the AR-VAST architecture can be expanded to allow for training and coordination with multiple weapon operators, phone talkers, and bridge teams for maximum training effectiveness, the current prototype addresses the primary issue of identification and marksmanship.

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PROTOTYPE DEVELOPMENT OF LOW-COST, AUGMENTED REALITY TRAINER FOR CREW SERVICE WEAPONS

Nathan W. Conger
Lieutenant United States Navy
B.A. Texas A&M University, 1998
M.S. University of Texas at Dallas, 2001

Submitted in partial fulfillment of the
requirements for the degree of

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September 2008

Author: Nathan W. Conger

Approved by: Mathias Kölsch
Thesis Co-Advisor

Joseph Sullivan
Thesis Co-Advisor

Mathias Kölsch, Ph.D.
Chair, MOVES Academic Committee

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ABSTRACT

A significant emerging threat to coalition forces in littoral regions is from small craft such as jet skis, fast patrol boats, and speedboats. These craft, when armed, are categorized as Fast Inshore Attack Craft (FIAC), and their arsenal can contain an array of weapons to include suicide bombs, crew-served weapons, anti-tank or ship missiles, and torpedoes. While these craft often have crude weapon technologies, they use an asymmetric tactic of large numbers of small, cheap, poorly armed and armored units to overwhelm coalition defenses.

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I. INTRODUCTION

A. SMALL BOAT ATTACKS

A significant emerging threat to coalition forces in littoral regions is from small craft such as jet skis, fast patrol boats, and speedboats. These craft, when armed, are categorized as Fast Inshore Attack Craft (FIAC), and their arsenal can contain an array of weapons to include suicide bombs, crew-served weapons, anti-tank or ship missiles, and torpedoes. While these craft often have crude weapon technologies, they use an asymmetric tactic of large numbers of small, cheap, poorly armed and armored units to overwhelm coalition defenses.

B. MOTIVATION

This thesis addresses two underlying problems. The first is the inherent danger to the U.S. Navy and Coalition ships from the FIAC threat, the types of FIAC are listed below in Table 1. These craft, with an arsenal which can contain an array of weapons to include suicide bombs, crew-served weapons, anti-tank or ship missiles, and torpedoes pose a considerable threat. While these craft often have crude weapon technologies, they use an asymmetric tactic of large numbers of small, cheap, poorly armed and armored units to overwhelm coalition defenses. The corollary issue is the training gap which exists for dealing with this threat.

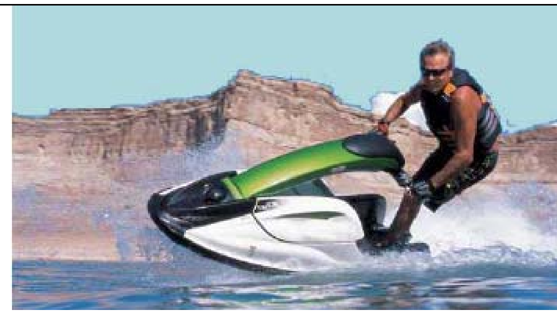
Type 1	Jetski or Boston Whaler with Rocket Propelled Grenade (RPG) weapons or a large blast bomb used in a suicide attack. Credited with a firing range of 3-500m, at which point the enemy is assessed as a 'leaker', who has achieved their mission objectives by inflicting damage on the Coalition force.	
Type 2	Larger 'Boghammer' class boat with an unguided multiple launch bombardment rocket, or a larger anti-tank guided weapon with a launch range of 8km, at which point it then becomes a 'leaker'. The craft has weather protection and accommodation. The small crew allows it to remain at sea overnight.	
Type 3	Small Fast Patrol Boat (FPB) typified by Super Dvora, with smaller anti-ship missile or torpedo armament, and a degree of sensor and Command and Control (C2) fit. Weapon ranges of 4 km (torpedo) out to 15 km (ASM) The vessel has more endurance than Type 2, allowing mission duration's of several days.	

Table 1. FIAC classes (Galligan, Galdorisi, & Marland, 2005)

In Figure 1 below, the real repercussions of ignoring the small boat threat are painfully illustrated. "On October 12, 2000, the USS Cole, an Arleigh Burke class destroyer, was attacked by a small craft loaded with 270 kg of C-4 explosives while making a routine refill stop in the port of Aden, Yemen. Steered by two Saudi suicide terrorists, Hassan al Khamri and Ibrahim al-Thawar, the small craft exploded alongside the USS Cole 47 minutes after the refueling was initiated, killing 17 U. S. servicemen and injuring 37 more. The attack caused $250 million in damage to the warship taking 14 months to repair." (Lorenz)

Figure 1. Damage to USS Cole from FIAC attack

The second issue to the small boat threat is the training gap that exists between current training methods and the emerging threat of FIAC to Coalition force protection requirements. Below, in Figure 2 you can see a 'killer tomato' which is the primary tool for our current training. We would like to show how, given the advancement of technology, we can provide the U.S. Navy, and Coalition partners an alternative training method which will provide the ability to identify, target, and destroy various artificial FIAC craft, and effectively bridge the current gap in training.

Figure 2. Deployed 'Killer Tomato'

The balance of this chapter is the reasoning behind why a prototype Augmented Reality system was developed. It outlines the threat, the training gap which currently exists, how the proposed solution bridges that gap, and explains why augmented reality is a good choice for such a trainer.

C. THE THREAT

The blue water navies of the world face a serious threat from FIAC. These craft range in size from small jet skis to fast patrol boats, and many kinds of civilian pleasure craft. The small boat or FIAC threat is ultimately an issue of staying power. Since World War II, the issue of staying power in the form of armor has been negated by the atomic bomb (Hughes, 1995). That means that staying power must come by other means. Those means range from ship design, tactics, and offensive power. Ship design, tactics, and offensive power are outside the scope of this thesis; however, the training in two of these function areas are of infinite importance, and can be enhanced with the lowest expenditure. The tradeoffs on these issues have been discussed for generations.

> You cannot have everything. If you attempt it, you will lose everything... On a given tonnage ...there cannot be the highest speed, and the heaviest battery, and the thickest armor, and the longest coal endurance (Mahan [28, p.44]).

"The problem now, as it was when Mahan wrote at the turn of the century, is to decide the proper mix of attributes in a modern warship" (Hughes, 1995). This is a problem faced by our enemys as well as coalition forces. Due to financial constraints on different countries, the solutions to this problem manifest themselves in different ways.

> A country can, or will, pay only so much for its war fleet. That amount of money means so much aggregat tonnage. How shall that tonnage be allotted? And especially, how shall the total tonnage invested in armored ships be divided? Will you have a very few big ships, or more numerous medium ships? (Mahan [27. P. 37]).

The United States Navy has answered this problem with a large number of large ships, in comparison with the rest of the worlds navies. Many our enemies cannot afford the amount of aggregat tonnage which the United States is willing to pay, and therefore their solution is Fast Inshore Attack Craft. The consequences of these decisions are evaluated in Section B in Chapter II.

D. WEAPON QUALIFICATION

There are currently no qualification requirements for Rules of engagement (ROE), marksmanship against moving targets, threat prioritization, target designation, field of fire coordination, coordinated arms effects, watch-station to CIC communications, or coordination with bridge maneuvering orders. Live fire exercises can approximate the bridge to weapon crew communications, but weapon effectiveness and marksmanship cannot be measured. Additionally, the cost involved with live fire exercises, and the limitations on the locations where these exercises are permitted do not allow crews to be trained in locations or with scenarios they are likely to face. Current qualification and training methods will be explored and evaluated in Chapter II.

E. PROPOSED SOLUTION TO TRAINING GAP

Trying to overcome all these limitations of current training systems, we devised a technological solution that addresses most of them. We will now briefly introduce AR-VAST: the Augmented-Reality Virtual at Sea Trainer.

We demonstrate that a prototype Augmented Reality Virtual At Sea Trainer can overcome many of the limitations of traditional training methods, and that such a system addresses the areas in which traditional methods fall short of our current needs. A fully developed AR-VAST system would be a deployable technology solution that uses in-place weapon systems as trainers in real-world environments with simulated enemy targets, and allow for training anywhere at any time. Chapter V outlines how the AR-VAST architecture can be expanded to allow for training and coordination with multiple weapon operators, phone talkers, and bridge teams for maximum training effectiveness. However, the current prototype addresses the primary issue of identification and marksmanship. A visualization of the AR-VAST system is shown in Figure 3.

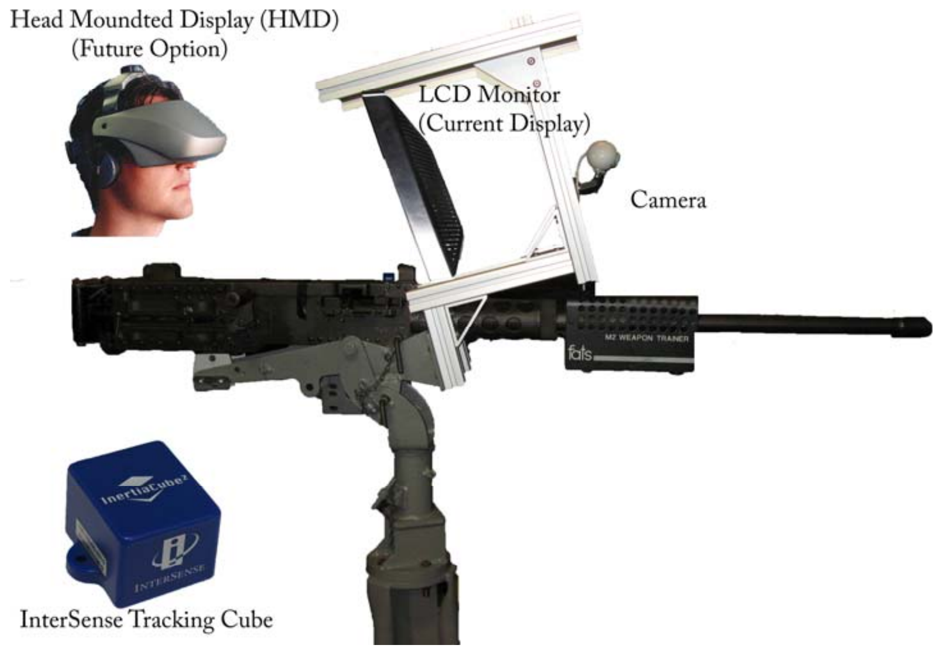


Figure 3. AR-VAST Concept

F. WHY AUGMENTED REALITY

Different technologies were investigated for this training need. It was decided to use augmented reality for a technological solution because it has the benefits of virtual reality without its limitations of cost, limited training environments and Virtual Reality Sickness. AR retains most of the important aspects of live fire exercises since it incorporates the real environment. It does so at a lower cost and with less danger involved, and with fewer restrictions for training locations than with live fire exercises. As a deployable trainer, it also has a distinct advantage over a static trainer, where the crews come to the trainer rather than the trainers coming to the crew. Finally, a robo-ski solution was investigated, but it suffers from the same limitations as live fire exercises with the added cost of potential loss of the robo-ski during training. We will address these issues in detail in Chapter II.

G. CHAPTER SUMMARY

The current training methods do not adequately address the emerging threats, and we have proposed a technological solution for this training gap. In the following chapter, we cover the background investigation which led to the conclusion there is a gap, the related work, and the technologies' current state of the art.

II. RELATED WORK

This chapter addresses the technology and procedures currently in use for training gunners, the methods for evaluating threats and damage, augmented reality technology, which we propose to use to improve VAST training, and rendering systems.

A. CURRENT QUALIFICATION AND TRAINING METHODS

As stated in Chapter I, it is our hypothesis that there is a gap in the qualification and training requirements now employed. This section will first examine and evaluate the current weapon qualification, and then the current training methods.

1. Weapon Qualification / Killer Tomato

The current training on heavy machine guns in the U.S. Navy does not address either the identification of targets, or the ability to destroy moving targets. The following is the description for the qualification for use of a .50 cal in the Navy's OPNAVINST 3591.1E:

> Course of fire is a six-phase, 100 round performance evaluation, fired on a 400-meter range (afloat or ashore) using an 8' x 8' size area target. Most military machine gun ranges ashore usually provide adequate area targets that can be used (i.e., old tanks, trucks, etc). For ranges at sea a 'killer tomato" or something of equivalent size placed at 400 to 500 yards will suffice. Any non-fired rounds due to weapon malfunctions shall be fired as an alibi. The machine gun will be fired from a mounted (free-gun) position with no T&E mechanism used. Each shooter will set Headspace and verify Timing

> before firing the performance evaluation. After the shooter has completed five phases of fire, the barrel shall be changed and Headspace and Timing set/verified again, which represents the sixth phase of the course of fire.

The first phase is to zero the weapon, or establish hold. The qualification on phase one is:

> With a 20 round belt of ammunition, on command, the shooter will LOAD, MAKE READY, and FIRE on the designated target in order to zero the weapon or establish a proper hold. The shooter must UNLOAD, SHOW CLEAR at the completion of fire.

The qualification is scored by the following criteria: Verify Headspace and Timing, Place Weapon in Condition 4, Zero or Establish Hold, and Unload Show Clear. All of these objectives are graded on a pass or fail basis.

Phase two is the engagement of a single target. The grading criteria for this phase are: Place weapon in Condition 3, Effectively Engage Target (15 Seconds), Unload Show Clear. The qualification on phase two is:

> With a 20 round belt of ammunition, on command, the shooter will MAKE READY and FIRE on the designated target utilizing multiple 3 to 5 round bursts while maintaining a consistent cone of fire and beaten zone to effectively engage the target. The shooter must UNLOAD, SHOW CLEAR at the completion of fire.

Phase three is functionally the same as phase two, but starting in weapon condition four instead of condition three. Phases four and five are both intended to qualify the individual on the reloading of the weapon, and phase six is the conducting of a barrel change. Table 2 summarizes the phases, purposes, and conditions for this weapon qualification.

Phase	Purpose	Distance	Rounds	Starting Condition	Starting Position	Sequence
1	Zero or Establish Hold	400m	20	4	Prone/Sitting-Tripod Standing-Mounted	20 rounds (3 minutes)
2	Engage Target	400m	20	3	Prone/Sitting-Tripod Standing-Mounted	20 rounds (15 seconds)
3	Engage Target	400m	20	4	Prone/Sitting-Tripod Standing Mounted	20 rounds (20 seconds)
4	Reload	400m	2x10	4	Prone/Sitting-Tripod Standing-Mounted	One 10 round belt reload one 10 round belt, reload time limit 20 seconds
5	Reload	400m	2x10	3	Prone – Bipod Standing-Mounted	One 10 round belt reload one 10 round belt, reload time limit 20 seconds
6	Barrel Change	N/A	N/A	N/A	Unload, Show Clear	Change Barrel Set/Verify Headspace and Timing

Table 2. Summary Table – Category II Heavy Machine Gun Performance valuation

Therefore, for Category II Heavy Machine Gun Performance Evaluation, there are no requirements for exercising Rules of engagement (ROE), marksmanship against moving targets, threat prioritization, target designation, field of fire coordination, coordinated arms effects, watch-station to CIC communications, or coordination with bridge maneuvering orders. Current training methods are limited to familiarizing the trainees with loading, firing, and clearing the weapon and static marksmanship training from a static platform. This highlights a gap in the training requirements and subsequently a gap in current training systems where a new training system could be employed.

2. Robo-Ski

A much more innovative solution is the Robo-Ski type trainer. There are currently three types of this trainer to include: the Robo-Ski, a remote controlled jet-ski, the Robo-raider, a remote control combat rubber raiding craft powered by a diesel outboard with autopilot GPS, and the Seafox, a 16-foot rigid hull inflatable boat (RHIB) powered by a JP-5 propulsion system.

The advantage of this training method over the killer tomato is that this target system can move through the water exactly the same way a real enemy would move. The primary disadvantage is that the craft cannot be targeted and fired upon directly. This system utilizes a tow rope to drag the actual target through the water. The issue is that in order to protect the Robo-Ski a long tow rope is used, the target does not behave correctly. A shorter rope can be used to avoid this unwanted behavior, but that puts the Robo-Ski in danger of stray rounds, or inexperienced trainees. A consequential issue is the cost of replacement if the Robo-Ski is damaged or destroyed during the fire exercise. The third disadvantage is that identification of the target (what is the target?) is trivial, and this does not exercise threat prioritization or target designation. Also, as with all live fire exercises, locations are limited. Lastly, the cost increases dramatically as more Robo-skis are used to simulate small boat swarm attacks.

B. EXAMINATION OF THE THREAT

This section is an examination of several studies and models used to illustrate the dangers of small boat attacks, and justification of development of new technologies to help counter this threat.

1. Hughes Salvo Model

This section describes a method of evaluating the dangers of small boat attacks, and a realistic example of the employment of this model.

Hughes proposed an extension to Lancaster’s equations, which specifies the casualties a firing force would inflict over a period of time, relative to those inflicted by the opposing force, to show the tactical consequenses of a ship that had the offensive power to destroy one or more similar ships with a single ‘salvo’. Below are the Aspects of the Hughes Salvo Model, and its assumptions. For the purpose of illustration of the dangers of small boat attacks we will go through an example problem with the Hughes Salvo Model. First, we will explain the model’s aspects and assumptions in Tables 3 an 4 respectively.

Offensive Power	Each warship has a certain offensive power it can project.
Defensive Power	Each warship has a certain defensive power it can use to counter the opponent's offensive power.
Staying Power	Each warship has a certain ability to withstand the offensive power of an opponent and continue to employ its own offensive power.
Salvos	A Salvo represents a complete exchange of offensive power, countered with defensive power, and the resulting staying power

Table 3. Aspects of the Hughes Salvo Model

Striking power is the number of accurate (good) ASCM (Anti-Ship Cruise Missiles) launched
Good ASCM shots are spread equally over all targets
Defense systems of a targeted force are flawless and w/out leakers until that platform's defenses are saturated
Staying Power: Firepower kill vice Sinking the ship
Hits diminish a target's fighting power linearly and proportionately to the number of remaining hits that ship can take
Weapon range sufficient on both sides, neither side has advantage
Losses, ΔA and ΔB, are measured in warships put out of action

Table 4. Hughes Salvo Model Assumptions

The Hughes Salvo Model is a series of equations. The first are the force-on-force equations for combat work achieved by a single salvo at any time step. These equations take into account the number of ships, the number of missiles fired per ship per salvo, the number of missiles intercepted by the targeted ship, the number of hits required to put a ship out of action to determine ΔA and ΔB, which are the losses each side suffers at each time step. These equations and their inputs are listed below in Figure 4.

$$\Delta B = \frac{\alpha A - b_3 B}{b_1}$$

$$\Delta A = \frac{\beta B - a_3 A}{a_1}$$

A, B : Number of ships

α, β : Number of missiles fired per ship

a_3, b_3 : Number of missiles destroyed per ship

a_1, b_1 : Number hits required to put ship out of action

ΔA, ΔB : Number of ships put out of action in salvo

Figure 4. The Hughes Salvo Model

To discover which side is the victor, the easiest way is to employ the equation in Figure 5, which determines the Fractional Exchange Ratio (FER). This equation factors in both the losses suffered from each side, the total number of ships on each side, and the defensive capabilities of each ship. If the FER is greater than one, then side A wins, and if the FER is less than one, then side B wins.

$$FER = \frac{\Delta B / B}{\Delta A / A} = \frac{(\alpha A - b_3 B)(a_1 A)}{(\beta B - a_3 A)(b_1 B)}$$

Figure 5. Hughes Salvo Model Results

In a real-world example, there may be two U.S. Arleigh-Burke Class destroyers versus six enemy Houdong-class patrol boats, which are Chinese built craft sold around the world. The model's assumptions and results are listed in Figure 6.

Number of Units	A - 2	B - 6
Staying power	a1 – 2	b1 – 1
Defensive Power	a3 = 16	b3 = 1
Striking Power	α – 24	β – 6

$$FER = \frac{\Delta B \quad B}{\Delta A \quad A} = 7$$

Figure 6. Hughes Example Results

The ΔA, the number of destroyers lost, is calculated to be 2. Meanwhile the ΔB, or number of enemy destroyed, is 6. Therefore, while the destroyers cripple all six of the enemy and have the capability to handle seven times the number of enemy, the U.S. ships are also taken out of action. This is evidence of how quickly, and with what numbers a Destroyer, or in this case a pair of Destroyers, can be target saturated. The stark contrast in loss of life and tax dollars between a U.S. warship and a small boat renders the loss of a single warship to an attack of this kind unacceptable. That these craft are fast, may have no identification markings, and can be heavily armed highlights two major concerns. The first is the identification and classification of these craft as a threat in real time is very difficult. The second is how to neutralize these small, fast moving targets after identification.

2. MANA Study of Small Boat Attacks

Galligan et al. (Galligan, Galdorisi, & Marland, 2005) did a study with MANA (Map Aware Non-uniform Automata) which is an agent-based model developed by the Operations Analysis group at Defense Technology Agency in New Zealand, and concluded that an a type I FIAC attack would have a 3 to 100% chance of a leaker, an enemy reaching their effective weapon range, depending upon the size of the swarm attack. They further concluded that for type II and III that the survivability of the blue force depends entirely upon the range of red forces weapons.

3. SMALL BOAT AND SWARM DEFENSE: A GAP STUDY

LT Andre Tiwari, of the U.S. Navy, is currently conducting a current capabilities gap study which attempts to determine if a gap in capability exists in the surface force to defend itself against small threat craft by using the Anti-Terrorism / Force Protection (AT/FP) Tool initially developed by Lieutenant James Harney and significantly enhanced by Lieutenant Patrick Sullivan.

4. Threat Summary

We have illustrated three examples of studies and models which highlight the threat of small boat tactics. To help mitigate this threat we would propose additional training in the area of Small Caliber Action Teams. To this end we are recommending the technological solution AR-VAST which can answer many of the gaps in current training methods.

C. AUGMENTED REALITY TECHNOLOGIES

Augmented reality is already in use in various ways we see every day. It was used to great effect during NBC's television broadcasts of the 2008 Summer Olympics, as the flags of the athletes' countries were superimposed on their swimming or running lanes, and as seen as the yellow line on National Football League television broadcasts.

A perfect example of AR for the war-fighter would be the Heads-Up-Display (HUD) in the cockpit of airplanes. This is an example of how aircraft data like altitude and attitude can be displayed in the pilots view frustum, limiting the need for the pilot to look at the actual instruments.

This section examines the state of the current technologies for use with an augmented reality system in general, and for AR-VAST specifically.

1. Display types

The first major design decision for AR-VAST is what display type to use. There are many display type options for Augmented Reality systems. These displays range from various Head-Attached displays such as retinal displays, head-mounted displays, and head mounted projectors; and Hand held displays such as cell phones to Playstation Portables; to spatial optical see-through devices such as video monitors, and stationary projectors. (Bimber & Raskar, 2005) Not all of these display types would be suitable for use in an application such as AR-VAST. First, the currently available retinal displays are only monochrome. This display type is good for informational purposes, but poor for realistic graphical displays. Second, hand held displays are too small and impractical for an application such as AR-VAST. Third, projection displays (Bimber & Raskar, 2005) would be bulky, and not usable in all lighting conditions, specifically when it is sunny. They also require projection on a suitable surface, which the ocean does not provide.

The two most suitable display types, therefore, would be a COTS flat paneled monitor, and a Head Mounted Display (HMD). Each mode of display has advantages over the other, and each has limitations from which the other technology may not suffer.

2. Tracking

Tracking requirements for an augmented reality system will necessarily depend upon the display type. For example, in the AR-VAST system, if a monitor is used, the only tracking requirement will be to track the weapon’s movement to translate real world movement into movement in the simulated environment. However, if the display is a Head-mounted system, then in addition to the weapon, the head will have to be tracked. There are also different types of tracking technologies, some of which may be more or less suitable for this application.

Another issue to influence which tracking technology to use is drift. Drift is an undesired change in output over a period of time that is unrelated to input. Inertial trackers are particularly susceptible to problems with drift due to the nature of their accelerometer sensors.

While in prototype, drift is less of a problem because all objects are internal to the system itself. However, later development will include objects which are outside the simulated world. An interaction between the real world and the simulated world will be achieved by placing “artificial” transparent objects in front of any real objects. This will allow for users to have the impression that they are in fact interacting with “real” objects. However, if there is considerable drift injected into the system by the tracking mechanism, the transparent objects will become detached from their real world counterparts, and the illusion will be lost.

The three options for tracking in an AR-VAST prototype would therefore be inertial tracking, feature or optical tracking, and some hybrid combining both solutions. Other options exist, but would not be suitable to this environment. First, magnetic tracking would be infeasible on a ship with degaussing, a method for eliminating unwanted magnetic fields. Second, ultrasonic tracking could interfere with ship systems. Lastly, external optical tracking for example with retro-reflective markers and infrared vision would necessitate external infrastructure in the form of a camera, and bright daylight performance is questionable. The source-less, self-contained inertia tracking is not subject to any of these disadvantages.

3. Blending Virtual and Real Worlds

One of the first AR applications which used the real world environment for first person shooting was ARQuake, developed at the University of South Australia. In this application, the physical world is modeled as a Quake 3D graphical model. This mapped model of the physical world is not rendered, but "the augmented reality information is rendered in special context with the physical world." (Thomas, et al., 2000) A GPS unit and head tracking are used to sync the real world with the modeled real world within the application. For AR-VAST we would like to advance this technology to divorce the system from needing a GPS device and needing to have the environment modeled before runtime.

D. GAME ENGINES

A game engine is a middle-ware software development tool kit that simplifies game and simulation design for rapid development. It frequently consists of the following components: rendering 2D and 3D graphics, physics, collision detection, sound, scripting, AI, networking, memory management, and scene graphs. A game engine provides a flexible and reusable software platform which provides all the core game functionality needed, right out of the box, to develop a game application while reducing costs, complexities, and time-to-market.

AR-VAST needs a game engine to provide the components needed to give the user a rich visual environment; endow AR-VAST with the necessary functionality for the physics of rigid body motion, ballistics, and particle systems; calculate collision detection; and give scalability with regards networking and confederation with other simulations.

There are many commercially available game engines available for use, but there is a vast degree of separation on price and functionality. There are also several open source game engines available that have issues on customer support, and may have limited functionality. Several examples of game engines and an example of a next generation game developed on that game engine are listed below in Table 5.

Game Engine	**Next Gen Game Developed**
Unreal Engine 3	Unreal Tournament
CryEngine2	Crysis
Dunia	Far Cry 2
Eclipse	Knights of the Old Republic II
Ego (formally Neon)	Colin McRae: DiRT
Essence	Company of Heroes
Euphoria	Star Wars: Force Unleashed
Frostbite	Battlefield: Bad Company
Gamebryo Element	The Elder Scrolls IV: Oblivion

Table 5. Common Commercial Game Engines

The cost of commercial game engines is not often publicly available. While an official request would have to be made to determine the actual development costs on those platforms, the licensing costs for any one of those game engines would not be trivial. In addition, the number of copies of each developed game to be deployed and the number of games to be developed would need to be disclosed before the total price could be decided. However, while the cost is high, customer service can be expected, and explicitly added to the contract.

To avoid the costs involved with commercial game engines, an open source game engine can be used. There are at least two engines which fit into this category: NeoEngine and Delta3D. NeoEngine has the advantage that is available for Windows, Linux, and MacOS X. This means that software can be developed on any of the three top computer platforms. Delta3D can develop games on both Windows and Linux platforms. Between the NeoEngine and Delta3D game engines Delta3D is the more accessible to NPS students as it was developed at NPS, the development team is co-located with the MOVES department, and is taught as part of the curriculum.

E. CHAPTER SUMMARY

This chapter has examined the current training methods, the current state of Augmented Reality technology, and evaluation of the FIAC threat. The following chapter will examine the design decisions which were made in the development of the AR-VAST prototype with justification for the technologies used in the prototype.

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III. SYSTEM DEVELOPMENT

This chapter explains the design choices and implementation of AR-VAST from concept to working prototype and beyond. The initial prototype specifications were kept intentionally simple. This would allow for the construction of a framework upon which to build successive iterations with a spiral software development life cycle. We decided on the following initial prototype milestones listed in Table 6 and additional functionality and effects for future development spirals as listed in Table 7.

1. Develop Program system framework (Delta3D integrated with tracking system IE inertia cube)
2. Develop an OSG model scene graph to include boat, .50 cal, static ocean model, and particle system wake and bow wave.
3. Weapon tracking calibration (inertia cube on .50 cal)

Table 6. Initial Prototype Milestones

ADDITIONAL FUNCTIONALITY
Realistic boat motion model
Firing weapon with trigger
Splashes and tracers rounds
Destroying enemy
Weapon effects
Dealing with real occlusions
Smoke effect to obscure vision due to firing .50 cal.
Force feedback from weapon firing
Scripted or AI target behavior

Table 7. ADDITIONAL FUNCTIONALITY

Currently, all of the initial milestones have been met. AR-VAST prototype development is at 140% completion as many of the additional functionalities have been added beyond the initial prototype requirements definition. As is likely with all new systems there has been some mission creep as additional functionality has become required during the development life cycle. Two of these major functions are: Firing hit/miss statistics, and using a validated ballistics model for round trajectories.

The rest of this chapter is a discussion of major design points, and how the prototype was developed along with how the additional functionality was achieved.

A. DISPLAY DECISION

For the purposes of the prototype development, two display types were proposed. These were a flat paneled Liquid Crystal Display (LCD), and a Head Mounted Display

(HMD). Below is a rationalization of the pros and cons of both choices, and the conclusion that we came to regarding the design choice.

1. Monitor

A traditional flat panel monitor has several advantages over an HMD display. The first advantage is cost. Lightweight flat panel monitors are becoming a commodity, as the technology is much more mature than HMD technologies. The second advantage is Field of View (FOV), where people have a 180° FOV most HMDs have less than 150° FOV. Additionally, a monitor can be moved closer or further away to change the FOV and resolution of monitors is much greater than the typical HMD's 10-20 pixels/°. Resolutions of 1900x1200 pixels are commonplace. The third advantage is that users would not suffer what is commonly referred to as Virtual Reality Sickness (VR Sickness). This phenomenon is caused by a conflict of signals between the eyes and the inner ear due to lag introduced by image rendering. (Johnson, 2005) With a monitor, VR sickness is less of an issue since the user can see the real world as well as the virtual world. The last advantage is that the design of the tracking functionality is a degree of difficulty easier as only the weapon needs to be tracked rather than the weapon and the user.

This solution also has disadvantages. The primary disadvantage being that a monitor is less immersive than an HMD. On the other hand, it is the lack of immersion that allows users not to suffer VR sickness. To make the monitor solution as immersive as possible and thus less likely to be rejected by users would be careful calibration between the user, the camera and the weapon. The camera should as closely as possible match the point of view of the user, and should be adjustable in both the depth and height diminutions. This requires that the camera be mounted on an adjustable frame or gimbal. The lighting between the real world and the virtual world may differ, as well as lighting conditions will change the visibility of the LCD screen. FOV is also problematic with an LCD screen, but may be overcome with how the LCD is mounted, possibly also with more than one LCD monitor. Additionally, the monitor should be adjustable as well to maximize the field of view to cover as much of the users view as possible. This would require a two degree of freedom of motion of the monitor in the depth and height.

2. Head Mounted Display

The primary advantage of the HMD would be that it is more immersive than a monitor. However, HMDs can cause Simulator Sickness more often than a monitor. (Johnson, 2005) This effect would be compounded if any image manipulation were to be used to create photo realistic wakes.

The disadvantages of an HMD would be cost, higher requirements on tracking accuracy, the discomfort of wearing an HMD, putting it on and calibrating it, Field Of View limitations, resolution limitations, jitter, brightness issues, and video- vs. optical see-through problems. Video see-through has limited resolution and field of view. Typical current technology is limited to 150° FOV and 10-20 pixels/°. Optical see-through was not viewed as an option because lighting conditions that are required for optimum viewing do not exist in the operating environment that AR-VAST would be expected to be used. Also, registration remains a high hurdle to clear for optical see-through displays since the real-world optical path has no latency at all, while no latency rendered imagery has yet to be achieved.

B. TRACKING DECISION

AR-VAST had three proposed tracking solutions. These were the InertiaCube2 (inertial tracking), feature tracking and a hybrid of both inertial and feature tracking. Below is an explanation of all three tracking technologies and

discussion of their benefits and limitations. Last, is the conclusion on which tracking choice to be used in the AR-VAST prototype.

1. Intersense InertiaCube2

"The InertiaCube^2 integrates nine discrete miniature sensing elements utilizing advanced Kalman filtering algorithms to produce a full 360° orientation tracking sensor." Not only does this tracker have 360° orientation, it also has a full three degrees of freedom in heading, pitch, and roll. However, this tracking system, while good in laboratory settings and initial development, has limitations which could make it in-appropriate for fielded use on ships. The major problem with using this tracking technology is that it uses magnetic correction for drift which is a byproduct of inertial tracking. However, this magnetic correction introduces more error because of the magnetic fields produced by the weapon and any ship onto which this system would be deployed. The effect of the magnetic fields on the operation of the system is extreme, even in the lab. The magnetic drift correction can be turned off, but there is still the problem of drift. To counter this, the inertial cube can be reset if the drift becomes too great during run-time, or the system can be re-calibrated between each use. The InertiaCube^2 can be seen in Figure 7.

Figure 7. Intersense InteriaCube2

2. Feature Tracking

Feature tracking uses the camera image to track identifiable features, and tells the system how much the angle and distance has changed from frame to frame. This could be much more precise than an inertial sensor, and does not suffer from the effects of drift. The main advantage is that we are trying to register or merge two images, and vision-based feature tracking uses exactly those images to compute the transformation. However, feature tracking does have a potentially serious drawback in this particular environment. Finding identifiable features to track could be a difficult problem when faced with an open ocean environment. There are different methods of feature tracking which could be used to achieve the necessary tracking, but the question of how this system will be deployed and used will have to be answered before the correct feature tracking method can be chosen. The short-term solution for this particular problem would be to have an option in a graphical user interface to tell the system what operating environment the system is being used in currently, and apply the correct feature tracking method based upon that input.

Additionally, if the future development includes a video see-through HMD and all tracking is done with feature tracking, then the decision must be made for the placement of the camera, and how to track both the head movement and the movement of the weapon. Ideally, the gun camera would have the same field of vision that the user would have without wearing the HMD. Tracking the weapon would then be done at the same time as the environment tracking using a similar process.

3. Combined Solution

Inertial tracking has drift issues, and feature tracking has potential problems with feature identification. Perhaps the best solution would be to blend feature tracking with inertial tracking. This would eliminate the complexity of tracking both the gun and the head with feature tracking, and inertial tracking’s issue with drift. In effect, it is complementing one’s weakness with the other’s strength.

This approach has already been established and tested by the Department of Computer Science University of North Carolina at Chapel Hill (Andrei State, 1996) amoung others.

4. Prototype Tracking Decision

In the initial prototype development, the Intersense InertiaCube[2] was used for the purpose of tracking the weapon. Availability and rapid development were the primary reasons for this choice. The feature tracking option was a desired addition to the prototype, and the source code has been added for future testing.

C. RENDERING

After the design decisions on tracking and the display type to be used, the first step in creating the AR-VAST prototype was to create a web camera display using Open Scene Graph (OSG). Since the game engine, Delta3D, uses OSG, it was be relatively easy to blend an OSG Orthographic camera rendering the video feed, and use Delta3D to render and control the 3D objects.

Of all the game engine options, both commercial and open source, the only engine with which we had any experience developing software was Delta3D, which was developed at NPS. This engine also provided all the functionality needed for the development of an AR-VAST prototype, and support was available from the Delta3D development team. This was therefore the engine that the prototype was developed with; however, future development of AR-VAST should be done with the game engine which will provide the best solution within budget. This may mean using a different game engine for final production.

1. Capturing Video

In order to capture the video, the Open Computer Vision (Open CV) API was used. An additional function had to be written to translate the image from OpenCV format to OSG format. The virtual OSG camera had to be set-up to render the captured image. This was done with an OSG scenegraph node called "Heads Up Display" (HUD) that takes as input the captured camera image and displays it as a texture on an orthographic projection in front of the OSG camera. This implementation allowed any OSG object file to be loaded in front of the HUD's projection of the captured image.

2. Creating Video Texture

The next step was creating a video texture instead of a single image. This was accomplished by creating a buffer in which each captured frame would be stored until a new frame was captured from the camera. The current frame would be used until notification of a new frame was received, and the new frame would be retrieved. Thus, a rapid exchange of still images was used to display streaming video.

3. Combining Video and Game Engine

The difficulty in rendering both the video HUD and the Delta objects was that the HUD was an OSG camera, and every Delta3D Application already has a default OSG camera.

The solution was to nest the cameras so that they render at the same time. This solved the problem where only one of the two, the Delta3D or HUD, cameras could be seen at one time, and made it possible to have video see-through AR with augmented objects created and controlled by Delta3D.

D. ANIMATION

Once the HUD and the Delta objects were both being rendered, creating appropriate objects such as small boats, various other ocean vessels, and boat wakes was the next step. Delta3D provides vehicles from the sourceforge web site (Sorce Forge, 2006). Several vessels were chosen from the downloadable files, and were made ready for the AR-VAST application.

1. Small Boat Animation

A cigarette boat was chosen to be the prototype 3D model for a target. We modified an existing model for use in the simulation so that the center of rotation is in the stern of the boat. That simplifies animating the turns such that the boat is pivoting by its stern as a real small boat moves.

Animating the small boat was accomplished by setting the boat’s transform during the pre-frame function with changing x and y variables. The amount of change depended on the heading of the boat. Using a unit length of 1 unit of change, the amount of x or y translation was determined by the following equations:

```
y = - (sin (( PI*(heading-90))/180.0));
x = - (cos ((PI*(heading-90))/180.0));
```

The subtraction of 90 degrees is necessary to properly align the mathematical coordinate system with Delta3D's coordinate system.

Once the x and y components are calculated, those lengths are multiplied by the current speed variable. Currently, speed and heading are adjusted during runtime with keystrokes.

To make the simulation more realistic, the turn radius and roll are dependent upon speed. Both maximum rates of turn and roll change based upon the ratio of current speed to maximum speed. Also, the pitch increases during acceleration, and decreases during deceleration.

2. Wake and Bow-wave Creation and Animation

Creation of a wake and bow-wave are vital to AR-VAST. Often these two visual clues are the only way to mark relative motion and speed of a craft through the water. There are different ways to meet this goal. The first and easiest way is to make a particle system, which emits particles to simulate the creation of a wake. The advantage of this method is that the faster the boat moves through the water, the longer the wake becomes. Therefore, the wake's appearance is directly linked to the speed of the boat, which is a good approximation of real boat wakes. The drawback is that the particles do not interact with the background image, and do not cause after effects such as ripples.

These effects were created with Delta3D's particle editor (pictured below in Figure 8). By experimentation with different particle systems developed in the editor and tested in a demonstration application, two different effects were created. The first is a wake that consists of two particle streams, each with force acting upon them to push them in opposite directions on the x dimension to give the spreading appearance of a wake. The life-span of the particles affects the length of the wake during run time. This is necessarily somewhat un-realistic because the time it takes a real wake to disperse completely is too long for this simulation, and would leave wake tracks all over the screen. This would detract from the primary reason of having a wake to give the gunner some visual clues to heading and speed.

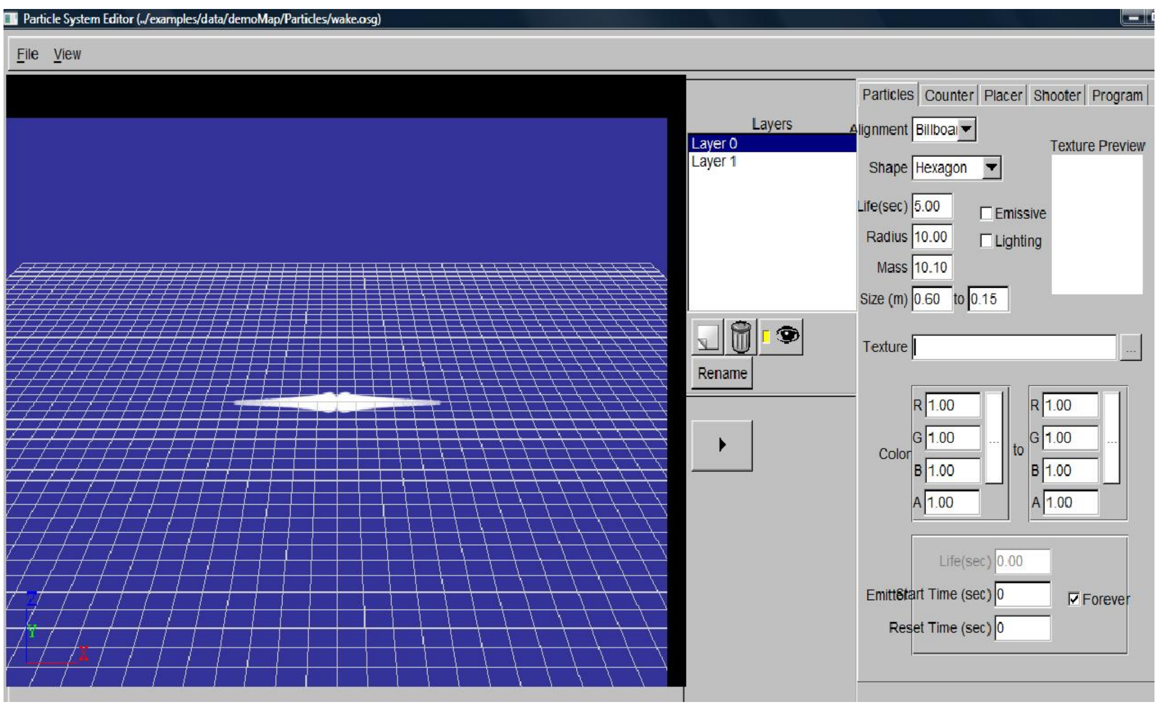

Figure 8. Wake Effect in the Particle Editor

The second particle effect is the bow wave, and illustrated in Figure 9. This system consists of seven layers. The first is a segment placer particle emitter used to simulate the prop wash from the rear of the boat. The remaining six layers are segment placer particle emitters of different levels of bow wave, which cane turned on or off dependent upon the speed of the boat. Multiple forces must act on each particle of these six emitters. One force in the x and another in the z dimensions are used to make the particles rise and fall in a manner similar to water particles being disrupted by the passage of the boat. The combined bow wave and wake can be seen in Figures 10 and 11.

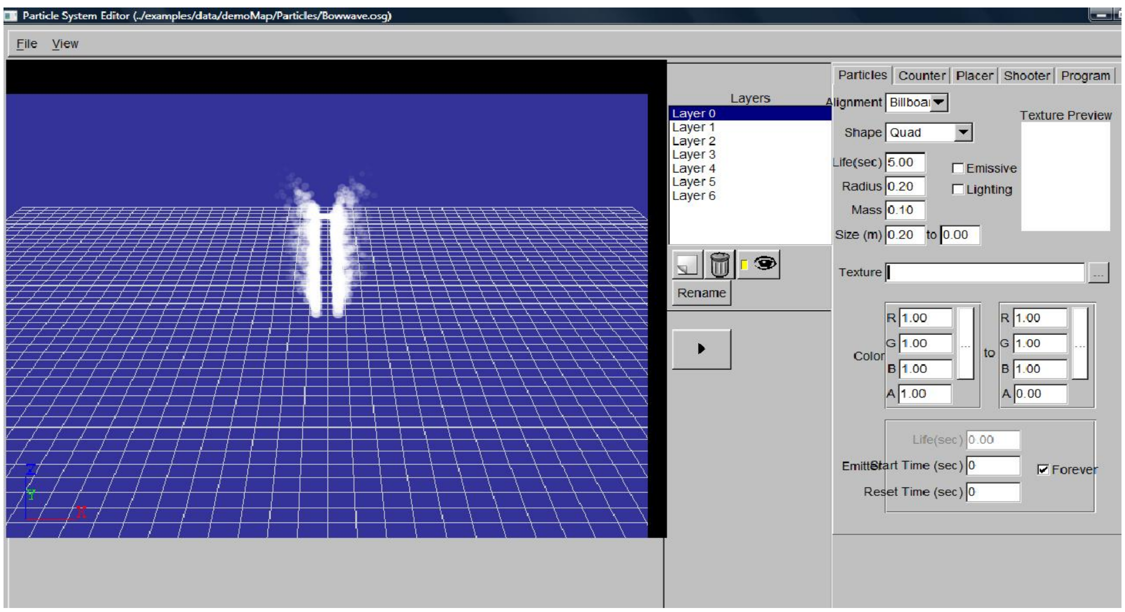

Figure 9. Bow Wave Effect in Particle Editor

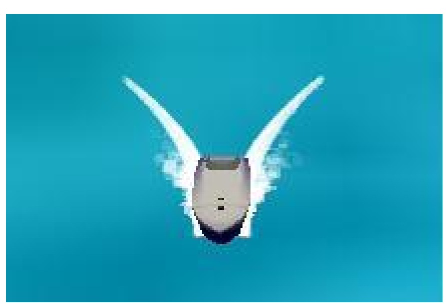

Figure 10. Example of a Particle System Wake from the Front

Figure 11. Example of a Particle System Wake from the Side

The second method is wake creation through image manipulation. This involves taking an image from the camera, before it was displayed to the user, and changing it during run time. As an example, Figure 12 shows a representative example of an image from what a deployed system could expect to see before any effects have been added. Figure 13 is a real wake formed by a speedboat. Using the real wake as a model, Figure 14 shows how Photoshop could be used to apply a simulated wake to the original image of Figure 12.

Figure 12. Sample Ocean Scene Image

Figure 13. Sample Real Wake Used as Wake Model

Figure 14. Simulated Wake Applied Using Photoshop

Between a particle emitter solution, and an image manipulation method of wake and bow wave creation, the particle system was chosen because it was a known technology which was easier to implement for a prototype.

3. Weapon and Camera Animation

Weapon and camera animation are tied directly to the tracking mechanisms. They are also dependent upon the display type being used. For the prototype, a flat screen monitor was used and only one tracking source was needed, the InertiaCube2. This means the camera and the weapon animations needed to be slaved to the InertiaCube2. To achieve this, the camera was added to the weapon as a child, and then translated in object space to an approximate sight picture from which a typical user might view the weapon in real life. The weapon and camera's rotation was changed before rendering (during the pre-frame) with an update from the InteriaCube2. However, the InteriaCube2's rotation matrix needed to be transformed o match Delta3D's xyz coordinate space.

4. Firing the Weapon

Instead of relying upon OSG to detect object collisions based upon collision geometry or a physics engine, a Delta3D proximity trigger is used to detect collisions between the small boat and other objects. The Proximity Trigger class contains a Trigger that it fires whenever a Transformable enters its bounding shape. All Delta3D Proximity Triggers have default collision geometry of a sphere set with a radius of 5 units; therefore, this was changed to appropriate collision geometry and size of the small boat. The proximity sensor was then filtered to collide with the appropriate objects by setting the collision collide bits for every category with which the trigger should collide. A Proximity Trigger is fired only once per touch of a Transformable.

A side effect of adding children, such as the wake and bow wave, to the small boat is that the bounding box for the small boat expands to encompass the small boat and all of its children. This requires that an empty root node be created as the boat parent, and the boat object as well as any additional objects such as wake and bow wave be added to the root. This allows for the creation of the boat’s proximity trigger with the correct dimensions. This trigger is then added to the small boat as a child, and translated in object space to cover the entire small boat’s dimensions.

Each time the weapon fires, a bullet object is created and added to a bullet queue. The bullet’s collision category bits are changed to match to collide with the boat’s proximity trigger, and its collision box dimensions are changed to have a width of .05m, height of .05m, and a length of 1000.0m. The objective with this approach is two-fold. First, this lays the groundwork for using a ballistic model for the bullet trajectories, as the necessary parts are already established, and just need to be modified for addition of more bullets and movement of the rounds through the simulation space along a ballistic trajectory. The second is that an arbitrary number of individual proximity triggers can be created to trigger different effects. For example, one trigger could be applied to the hull of the small boat which when hit changes the boat’s handling dynamics or make the boat sink lower in the water, while another trigger can be attached to the engines which would affect the speed of the boat, and could start to smoke when hit. Other methods of collision detection do not allow for this level detail with the effects. For tradition collision detection methods, the boat would have to be split into its component parts to allow for the same level of detail, but this could increase the complexity of the animation process.

E. ENEMY TARGET BEHAVIOR

There are several options for enemy behavior models. These options may be constrained by the number of targets to be controlled. The two options discussed here are: a human in the loop option, where a person drives a target in the environment, and different methods for an artificial intelligence option.

1. Human in the Loop

With a human in the loop system, the easiest solution is to have only one enemy target. This limits the complexity of the system and the number of people needed to operate at full capacity. The prototype was built to this specification for these reasons. This oversimplifies the task of marksmanship and target acquisition, however, and does not address most of the other target training objects.

It is possible to scale this system to have multiple input devices and multiple windows such that a different person operates a separate target up to an arbitrary number of targets. This would be an interesting solution for several reasons.

a. Dual Use Trainer

An interesting aspect of a human in the loop multi-user solution would be that it could be as a dual use trainer to train small boat drivers. Experiments could be conducted for effectiveness with different levels of coordination or communication between the small boat drivers on one side and multiple gunners on the other, as well as different numbers of enemy targets and gunners to find optimal attack vectors and defensive strategies with real subjects.

However, this approach would be best suited to a lab environment. As this is designed to be a deployable trainer, a more compact and less user intensive route should be taken for the deployable version. However, this could be an intermediate step towards an artificial intelligence solution by finding the behaviors that are most successful, and trying to automate those behaviors. Also, the necessary target-to-gunner ratio needed to either defeat an attack, or to overwhelm the defenders could be explored.

2. Artificial Intelligence

The current AI module for the AR-VAST prototype an A* search algorithm, included in the Delta3D game-engine, for waypoint planning. It is implemented with a waypoint map where the small craft moves from point to point with an A* search algorithm with the destination as one of many points on the Destroyer from which the gunner is firing. For this AI solution, a reset function has been written so that the starting position of the small craft is randomized to make sure that each run is unique.

This approach gives the small boat some intelligence, but does not allow the small boat to behave in any way that is not predictable. In Chapter IV, we will discuss two options for intelligent AI. The first is an agent-based approach which, if implemented, will simulate both enemy and neutral virtual vessels as well as allows behavior switching to allow for deception. The second is using an existing JSAF AI module.

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IV. AR-VAST EVALUATION AND FUTURE DEVELOPMENT SPIRALS

Goal of this chapter is to make a system recommendation and to provide a detailed plan for implementing a packaged AR-VAST product.

The evaluation and design plan for AR-VAST is delineated into two categories. The first category and the most important at this stage of AR-VAST evolution is making design decisions based on a system engineering approach. The second category is possible improvements to the functional areas of AR-VAST.

A. SYSTEM ENGINEERING AND ANALYSIS

In the following, we describe our approach for putting forth a systems engineering approach to the next development spirals for AR-VAST. This approach has its roots in standard engineering and planning practices which we applied to the specific system at hand. We validated our approach with a recognized expert at this task and experienced system developer.[1] Guaranteeing system success is impractical for larger systems and spiral development by definition means periodic re-evaluation. Hence, the recommendations stated below should be re-evaluated frequently. However, we hope that our three-pronged approach of following established practices, validation with experts, and benefiting from our personal exposure to the problem will mitigate many risk factors and help future system development.

[1] Dr. Mike McCauley, personal communication, August 2008.

AR-VAST needs to be developed in a "technologically-based process encompassing an extension of engineering through all phases of the system life cycle; i.e., design and development, production or construction, utilization and support, and phase-out and disposal." (Blanchard & Fabrycky, 2006)

The prototype has proved that current technology can achieve a certain level of visual fidelity in an augmented reality simulation, but thus far the human system has been largely ignored. For AV-VAST to go beyond prototype, the prototype and the assumptions made during its development need to be put aside. For this system to be viable, a system engineering approach which takes into account the whole system life-cycle, and not just development life-cycle, must be used.

There are many different system engineering approaches for system design. Here, we strive for a generic outline of the path that AR-VAST should take to make sure that all areas of system design are addressed, and design decisions are made intelligently up-front rather than when any changes have much higher financial and time costs.

1. Conceptual System Design

The first step is to conduct a conceptual design, which is an early and high-level activity where many design choices are made, potential problems are addressed, and the time-line established. According to Blanchard and Fabrycky (Blanchard & Fabrycky, 2006) the following are the steps which need to be taken or considered:

- Identifying problems and translating them into a definition of the need for a system that will provide a solution;
- Accomplishing advanced system planning in response to the identified need;
- Conducting a feasibility analysis leading to the definition of a technical approach for systems design;
- Developing system operational requirements describing the functions that the system must perform in accomplishing its intended mission;
- Proposing a maintenance concept for the sustaining support of the system throughout its planned life cycle;
- Identifying and prioritizing technical performance measures and related criteria for design;
- Accomplishing a system-level functional analysis and allocating requirements to the various subsystems and below as applicable;
- Performing system analysis and producing useful trade-off studies;
- Developing a system specification; and
- Conducting a conceptual design review.

Some of these steps have already been addressed through the development of the prototype, such as conducting a feasibility analysis leading to the definition of a technical approach for systems design. We know that

Augmented Reality technology can work, but is AR the right solution for the training need? The most important question that has yet to be answered is: How do we fill the training gap?

Next, a human factors study should be conducted to ensure that technology is the right solution for the training need. For this, a top down functional analysis needs to be done, and a training requirements document needs to be developed so that the technology trains a user in all the desired functional areas, as well as defining areas where the graphical display is most needed. For example, how does the typical gunner hit the targets? Does one use the optical sight, tracers or the splashes as the rounds strike the water to "walk" the rounds onto the target, or use some other method? All of these questions need to be answered before a fully fleshed out version of AR-VAST can be created.

A task analysis needs to be done on all the functions which will be required of the trainer such as: loading, firing, target selection, and successful shooting of targets with the .50 cal, or unintentional damage to neutral targets. Therefore, the next step is finalizing the system requirements and what functions AR-VAST will have. This will involve speaking to real weapon crews, and doing functional analysis of each function that will be required. Without this, AR-VAST is simply a toy video game product with no training value.

B. SYSTEM IMPROVEMENTS

1. Number of Targets

The ability to first add more targets in the simulation, and second to allow that the user or system administrator to control this variable is vital to the future development of this system.

The recommended solution is to create a queue of boats rather than a single entity. The number allowed in the queue should be decided by the training administrator before the simulation begins within the user interface. Creating a user interface, which utilizes a slider or some other input which allows the system administrator to know the maximum number of boats allowed by the system, as defined in the architecture would also be beneficial.

The ability to add more small boats also adds challenges to the application. First, a "Factory" design pattern should be used to create boat objects and encapsulate all the information that a small boat needs to have such as the maximum speed, pitch, and roll coefficients. A control will also need to be implemented which will iterate through the process to animate each vessel in the boat queue in turn.

2. Rendering

There are many variables that may need to be controlled manually or automatically before or during runtime to adjust the rendered view as needed to account for many real world conditions that will arise during normal operation of the AR-VAST system.

a. Weather and Lighting

The first of these variables is weather. Delta3D is capable of displaying different weather conditions. Fog is a good example of a weather condition which might be present with deployed systems. If there is no fog control on the user interface, then the real world view will show fog, but the augmented virtual objects will be completely un-obstructed by the fog. This will ruin the illusion of reality, and provide both negative training and a false sense of security by being able to fire at the attacking boats which should be obscured by the fog. This would also apply to nighttime operations. So, either a control for both lighting and weather must be implemented so that a user can adjust them to match the environment, or some type of automated function needs be created such that the system calibrates to the current weather and lighting conditions during runtime.

b. Sea State

Consideration must be given to different sea states under which the system might be called upon to operate. Under higher sea states, the movement of the small craft on the ocean will be un-realistic without any type of sinusoidal motion. The difficulty is matching the sea sate, the location of the waves, and the rendering of the simulation. The alternative would be to ignore the problem and to make training restrictions to certain sea states. The limitation of training in lower sea states would still benefit users with an HMD. The gunner, gun and AR-VAST display themselves naturally experiences the sea state and resulting motions, this does not have to be simulated.

c. Lines of Demarcation

A further rendering improvement that should be considered for addition are lines of demarcation. This would allow any gunner to know precisely when any craft came within specific ranges to their ship. This would be a similar technology to the National Football League's yellow first down line. Several line recommendations would be a ring for .50 cal's effective range, and a ring for each of the ROE's ranges.

3. Display

Based upon the outcome of the training requirements documentation, the display type will have to be tested in operational environments. The LCD monitor mounted on the .50 cal may not be the appropriate technology solution if it is decided that the force feedback is a necessary requirement for proper training. The violent motion of the firing of the weapon may destroy the monitor. This motion may also shake the user so violently that the HMD is unusable, either due to the users' inability to focus on the display as it moves, or by shaking the HMD from the users. In either event, any display solution would need to be hardened for the shaking involved, and the harsh operating environments.

4. Tracking

The final decisions about tracking will be based on the final decision about the display type, and testing and evaluation studies. These studies need to show that the chosen tracking system can track with sufficient precision and accuracy and speed such that it enables apparently seamless mixing of real and virtual environments. The goal is that trainees and experienced gunners alike accept the system with no issues with the tracking system. A cost benefit analysis will also be required for each potential tracking option. The bottom line is that if a monitor is used as the display device, then all that is needed is a single three degree of freedom tracking system for the weapon. If however, the HMD is the display device, then a three degree of freedom tracker for the weapon, and a six degree of freedom for the head would be required.

5. Ballistics

For AR-VAST not to provide negative training, a realistic ballistics model needs to be applied to the rounds fired from the weapon. Without this, the firing projectile flight path is a straight line, and the rounds could pass through any object to still hit the target. The round's model is already in place, and what needs to be applied is the physics behind a round traveling through space.

A number of different solutions are available to provide this functionality. The first would be the Open Dynamic Engine, an open source physics engine which is provided with Delta3D. The second option would be to use an existing Semi-Autonomous-Force (SAF) ballistics model using HLA to link the SAF to AR-VAST. The third option would be to buy a proprietary physics engine such as Havoc Physics, and use that in place of ODE. Each option would have advantages and disadvantages, and their own implementation issues, discussed here briefly.

ODE is an open source physics engine, and has limited support and may not have all the functionality or fidelity that may be required. SAF has registration issues, which is where an object in SAF space does not match exactly to the same objects location in Delta3D space. This would cause the weapon rounds to be inaccurate. A proprietary physics engine would have problems being integrated into Delta3D, and may be too costly to implement.

6. Real and Simulation Interaction

Augmented Reality, while having distinct advantages over Virtual Reality, has unique challenges which must be addressed before the technology can be fully realized. The largest and most important advantage but also challenge is the ability to interact with the real objects in the environment.

The AR-VAST prototype made inroads into merging real and virtual environments, but there are many more aspects that could be fused, or fused better. For example, while we implemented video scenery backdrop, gun pointing tracking, and boat physics on an approximated ocean surface, aspects such as ammo interaction with the ocean surface and appropriate virtual weather simulation were outside the scope of this prototype. If these challenges can be overcome, then this product would far surpass any trainer or system is this area.

A first step towards a solution would be for the camera to pan across the environment during runtime, and to recognize solid objects such as piers. The system would drop corresponding, virtual geometry over those objects so that simulated objects could collide with them, The virtual geometry would not be rendered (transparent color) and only used for collision detection, creating the appearance as if the simulated objects interacted with the real world. Admittedly, this is not a trivial undertaking. Work has been done with creating virtual objects from real objects already, and it is one more step to manipulate those objects within the AR-VAST simulation. (Brahim Nini, 2005) Some of the major complications are with recognizing real-world objects and their 3D structure, putting the transparent shapes in to the simulation at the right depth, and registering those shapes to their real world counterparts.

7. Realistic Artificial Intelligence

An AR system such as AR-VAST, which could be used in any geographical location around the world, has interesting and challenging problems for artificial intelligence for the behaviors of the attacking craft. A primary problem is the mismatch between the real geography and the virtual environment. For many typical AI procedures even as simple as path scripting, a priori knowledge of the game environment (its geometry) is needed. Canned behaviors would not be suitable for a system where the environment is not known until runtime. Additionally, areas of cover may or may not exist, and their existence depends upon the ability to incorporate real space objects into game-space. Secondly, real FIAC attacks need to be studied to identify common, unsuccessful, and successful behavior models.

a. Cognitive Agent AI

In an ocean environment where there are potentially no real areas of cover for an enemy to hide behind, a tactical A* search, or a path scripting method will not necessarily be the best method for AI. In this instance, where target identification is being trained concurrently with marksmanship, it is not just the location of a Non-Player Characters (NPC) that needs to be modeled or scripted, but the many higher-level behaviors which are employed by our enemies that need to be portrayed by the NPC. For the most lifelike solution for AI in AR-VAST, the small craft need to be aware of their environment, and be able to adapt to the current situation to exploit opportunities. This will require a cognitive approach where the agents' behavior is scripted, and that behavior can be switched based on environmental conditions. This approach has already been pioneered by Kok Tan and John Hiles in Kok's thesis: A Multi-Agent System for Tracking the Intent of Surface Contacts in Ports and Waterways. (Tan, 2005)

This AI behavior is achieved using the Connector-based Multi-agent Simulation Library (CMAS) developed by John Hiles and his students at the Naval Postgraduate School. The CMAS library has been used in projects such as the US Army game "Soldiers" and Project IAGO (Integrated Asymmetric Goal Assessment). The CMAS utilizes two types of tickets. Tickets are "a mechanism for encoding procedural instructions for agents as well as to provide an internal data organizing system. The first are data tickets, which are used to organize and ascertain the completion of hierarchical tasks. The second are Procedural tickets, which are used to generate the appropriate behavior based upon environmental conditions and status or state of other agents"(Tan, 2005).

For AR-VAST there would be two basic procedural tickets, or initializations. These behaviors would be neutral, and belligerent (enemy). Each basic behavior would also have several tactical behavior options. For example, the neutral tactical options could include: fishermen, service ships (replenishment ships), leisure craft, and neutral shipping. The belligerent tactical behaviors would be split again into active and passive. The active behaviors could include collision, small caliber weapons, and missile or torpedo weapon attacks. The deception behavior would mimic one of the neutral behaviors until such time that the conditions exist for the behavior to switch to an active attacking behavior. The various ticket types are listed below in Table 8.

Ticket type	Sub-categories	Tactics	Offensive Capabilities	
Neutral		Fisherman Service Tourist Neutral-Shipping	Ranged Weapons	Small Caliber Weapons
			Collision	
Enemy	Active	Ranged Weapons Collision	Ranged Weapons	Small Caliber Weapons Torpedoes Missiles
	Passive	Imitation	Collision	

Table 8. Agent Initialization

The specific conditions for a switch from a passive behavior to an active behavior would depend upon the craft's offensive capabilities. If the small craft is limited to colliding with the user's ship, then a plausible condition would be that its distance from the ship is not greater than the distance the craft would need to reach top speed. The reasoning is to have the enemy craft as close as possible to the target ship without alerting the ship of any hostile intent for as long as possible while still having enough time to reach top speed, and inflict maximum damage.

This method also allows for the possibility that a neutral craft will meet the conditions to switch to a belligerent behavior if certain conditions are met. These conditions could be that the user fired at a neutral ship, and that ship has the capacity to cause damage to the user's ship. If these conditions are met, then the neutral will get an enemy ticket, and their behavior will change accordingly. However, if the conditions are not met and the neutral craft has no offensive capability, then the neutral ship will remain neutral, and will try to avoid fire.

Additionally, an enemy target may never exhibit an overtly threatening action. If the conditions are never met for a passive enemy to change to an active enemy, then there is never an attack made, and the enemy would survive to fight another day. This allows for the behavior for the enemy to look for targets of opportunity while not showing hostile intent until a time when the environmental conditions are sufficient for an active attack to take place.

Each ticket or frame will be comprised of blocks. Each block will have three parts: conditions, behavior, and transitions. The conditions are the mechanisms to allow ticket transitions. They will be dependent upon the agents' capabilities assigned at the agents' initialization. Figure 15 illustrates a typical transition from frame to frame in a four frame procedural ticket in which the agent acts in a liner manner to reach its goal. Figure 16 illustrates how an agent can switch from one ticket to another when the environmental conditions exist for the agent to reach a higher priority goal.

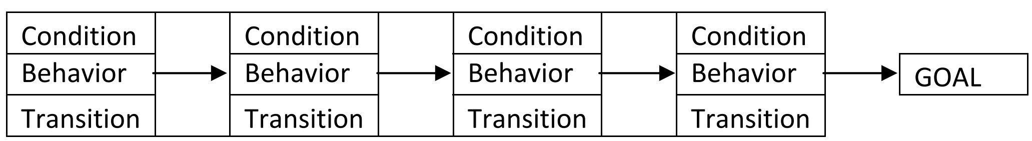

Figure 15. General Four Frame Ticket with linear transitions

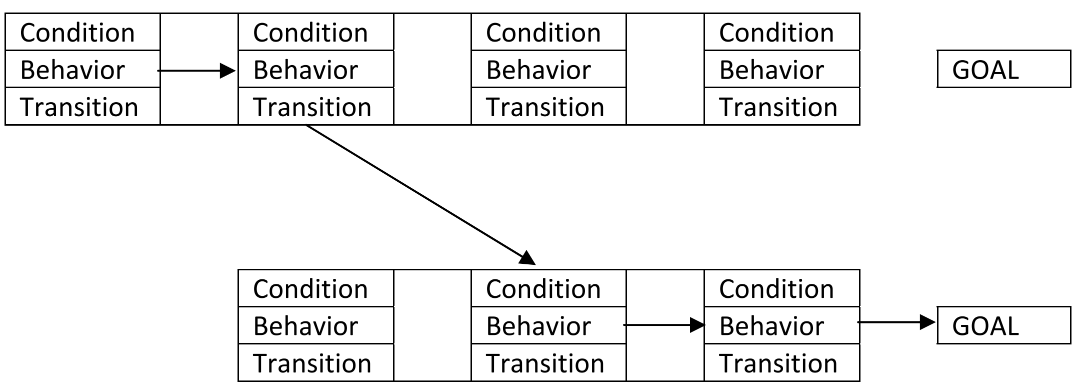

Figure 16. Four Frame Ticket transition to Three Frame Ticket

The last piece is communication between agents to allow for coordinated attacks. The communications is also achieved using the CMAS Library. The basic elements of agent communication are connectors. These connectors are like an outlet and a plug, either of which can be extended or retracted, and act as conduits to broadcast to or receive state information from other agents. This design is illustrated in Figure 17.

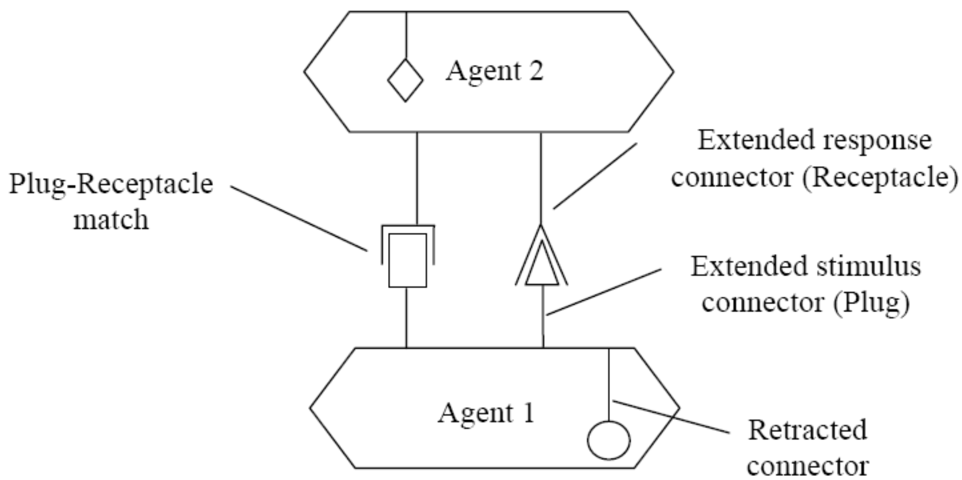

Figure 17. Connectors for agent communication and coordination

This design will require a significant amount of set-up before the simulation can begin. The user or system administrator would make a decision before run-time about how many artificial ships will be in the simulation, what the split between neutral and belligerent ships will be, and if the belligerent ships actions will be coordinated, or independent. All of these factors will contribute to the difficulty of the simulation.

b. JSAF AI

Another option for intelligent AI which could provide intelligent behavior with potentially less coding would be to utilize the JSAF module. Since Delta3D is capable of passing information with HLA this implementation is feasible.

8. Force Feedback

Some system of force feedback needs to be developed. There are three possible ways to accomplish this task. The first would be using real ammunition, the second would be to use blank rounds, and the last alternative would be to use a compressed gas such as CO_2.

The first two methods are virtually the same, except live ammunition would again limit where training could take place, but would exercise the re-loading of the weapon. Blanks also exercise this, but enable a ship’s crew to exercise in any environment. Both of these methods would incur additional costs as ammunition was expended.

The other option would be to use CO_2 similar to the ISMT trainer which the U.S. Marines currently use. For the ISMT, the weapons have been modified to use compressed CO_2 to simulate the firing of the weapon. This option would have a large start-up cost to retro-fit the fleet’s weapons to accept CO_2, but the operational costs would likely be cheaper to refill the CO_2 tanks than to purchase either live ammunition or blank rounds.

V. SUMMARY

A. WHAT IS NEXT?

The next step is to begin the Conceptual System Design Process as prescribed in Chapter IV. It is important to follow a system design process so that all aspects of the design process are considered, and no part is forgotten or marginalized.

B. DESIGN RECOMMENDATIONS

Summarizing the analysis and evaluation from Chapter IV, there are seven functional areas that need improvement: number of targets, rendering, display type, tracking, ballistics, real and simulation interaction, and artificial intelligence. The recommendations for improvement are made now without knowledge of the results of the functional analysis and problem definition.

The number of targets must be variable, and include both enemy and neutral vessels. This is required if target selection is a function AR-VAST is supposed to train. Otherwise, it is only necessary to incorporate multiple targets to try to overwhelm the user’s ability to destroy all targets before they reach their weapons’ effective range.

The incorporation of real weather and lighting conditions must be accomplished. Without this, the virtual targets will be rendered in daylight with perfect visibility despite the real weather and lighting conditions. These processes either can be automated (preferred but more difficult), or manually controlled before the simulation begins.

Experimentation with different display types must be done in both laboratory and real world environments to determine what display will provide the best solution.

Finalization of the display type is necessary before the finalization of the tracking system can be accomplished. However, a good candidate solution is that a combination of visual tracking and inertial tracking, and the implementation of this blend must be worked on in anticipation of the display type selection.

Real ballistics must be implemented. Of the options available, using ODE, the physics engine within Delta3D is the logical choice. Incorporating ODE with the prototype will be less problematic and less expensive than either using SAF ballistics, or using a third party proprietary physics engine. Once AR-VAST has ODE physics implemented in the firing of the weapon, test and evaluation of the physics will be required to ascertain if the physical model will achieve the training requirements.

If possible, the improved blending of real and virtual objects needs to be accomplished. This will provide a much richer and fulfilling training environment. If this is not possible, restrictions on where training can take place must be established. However, that would defeat one of the primary goals of AR-VAST, which is the ability to train anywhere.

Finally, an Artificial Intelligence system must be created specifically to the unique needs of AR-VAST. These are: a training environment where the number of objects and areas of cover are unknown beforehand; targets include both enemy and neutral vessels; targets include both real and artificial objects; target behavior can change dynamically; and enemy targets may act in unison or individualistically. This will require an AI system where the targets, or agents, are aware of their environment and the actions of the other agents.

C. SUMMARY

The primary focus of this thesis was to show a gap in training methods, and to propose a technical solution to this perceived training need. The secondary focus was to develop a prototype of the proposed solution to prove that Augmented Reality is a viable technology that is mature enough to provide the elements required of a fully functional training system that bridges the gap between the need and current deficiencies.

In addition to prototype development / proof-of-concept demonstrator we developed in this thesis a roadmap for further work upon the AR-VAST system. Implementing the roadmap will allow AR-VAST to be fully developed into a deployable system that will enhance the security and operational readiness of U.S. and Coalition forces.

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