THE DEVELOPMENT OF A NAVAL VIRTUAL TARGET RANGE

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ABSTRACT

This paper reports the development of a Naval Virtual Target Range (NVTR) lab prototype. Due to current political and environmental reasons, land-impact, live-fire training opportunities have become increasingly difficult for all branches of the armed forces, especially the U.S. Navy. Consequently, the readiness of the force suffers. The advancement of microelectronics, computer software technology, and modeling and simulation techniques provides a viable solution to this urgent need. A virtual target range can provide almost unlimited training opportunities in any open-ocean environment. In addition to supporting live-fire training, the system also allows for a combination of simulation and/or live-fire training from the lowest single unit to force level exercises. Substantial cost savings from deployment, preparation, and hardware wear and attrition, and high safety standards can be achieved through the use of this virtual target range. A lab version prototype system has been built using commercial-off-the-shelf components. This modular lab prototype can be used as either a stand-alone unit, or as a built-in component for existing naval gun weapon systems for testing and training in a controlled environment. This architecture allows the insertion of different components/subsystems for system upgrade and enhancement. Using a completed system, the Naval Surface Fire Support (NSFS) Team (gunner, forward observer, mission planner(s), fire controller, and commander) can conduct either simulated or live-fire training exercises. This paper reports the concept formulation, early analytic work, algorithm development, computer simulation, component construction, lab tests, and prototyping of a Naval Virtual Target Range lab prototype. The potential applications of this system are also discussed in this paper.

BIOGRAPHIES.

Omar Khan is currently working as a Senior Systems Engineer at United Defense. Mr. Khan has played a key role in launching many research and development projects and has introduced emerging technologies like Rapid Prototyping, Immersion Solutions and Wireless Control Capabilities to the existing weapon simulation systems. He has a BS (Hon) in Electrical Engineering from the University of Engineering, Lahore, and an MSEE in Computer Systems Engineering from Cleveland State.

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Al Sleder is currently the Systems Engineering Manager for the Armament Systems Division of United Defense. Mr. Sleder has over 17 years of Army combat system development experience including analysis and development of tactics, techniques & procedures; towed, self-propelled, rocket and missile combat systems; and command & control systems. He has taught mathematics at the US Military Academy and the University of Nebraska. Mr. Sleder has a BS in Engineering from the US Military Academy and an MS in ORSA from Georgia Tech.

Paul Huang has a wide engineering experience in electro-hydraulic systems, sensor and servo systems, communication systems, robotics, system integration, and modeling and simulation. Dr. Huang has worked on many naval and army weapon systems. Dr. Huang is a former artillery officer and has taught at several universities before joining the industry. He received his MSEE and Ph.D. from the University of Minnesota.

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INTRODUCTION

To maintain the readiness and proficiency of the forces, regular training exercises are indispensable for all modern military branches. Training exercises involve heavy investment in equipment, manpower, and facilities. In addition to the attrition and wear of expensive military hardware and manpower expenses, the specialized live-fire training facilities would create significant environmental impacts that are frowned upon by the general public today. All of those add substantial burden to the already stretched budget, schedule, and manpower requirements of military organizations.

The advent of high-speed computers and advancements in modeling and simulation has revolutionized the engineering community. This change has not only impacted on the engineering practices and the end products but has also directly influenced how the end users will use those products. The fast tempo of microelectronics and computer software advancement in everyday use has transformed the general public into relatively sophisticated users of complicated electronic equipment and computer systems. All of those changes have provided many new opportunities to address old problems. Modeling and simulation has been used in many applications that required significant resources, manpower, and high-risk tasks to achieve. Those include the launch of space vehicles, nuclear tests, and flight training, to name just a few.

Modeling and simulation has been used for training with a certain level of success. Computer-generated small weapon training facilities have been used as augment aid for live-fire; flight simulators are widely used to train pilots, various trainers have been used to train drivers of other vehicles, and the operation of complicated weapon systems can be trained through appropriate weapon system trainers or simulators.

A serious problem encountered by the US Navy today is the eminent risk of losing its live-fire training facilities. The near-term closure of the US Navy live-fire facility at Vieques Island in Puerto Rico will hamper the readiness of the Atlantic Forces. The threat to interrupt the use of the Pacific Missile Range Facility at Kauai, Hawaii by some environmental organizations may also have significant negative impact on the force readiness of the Pacific fleet. How to derive a feasible solution to this eminent problem in a timely manner is of paramount importance. This paper describes the development of a system that addresses the problem by utilizing a Virtual Target Range to support Naval Surface Fire Support mission training.

BACKGROUND

Naval Surface Fire Support (NSFS) is a significant element in naval operations. It is extremely important for littoral warfare and the tenets of ‘Operational Maneuver from the Sea’ and ‘Ship to Objective Maneuver’. The support of forces ashore depends heavily on the fires from the naval surface combatants. The accuracy of the gunfire, much like the accuracy of aerial bombardment, becomes more important given the nature of how future battles will be fought. Special Operation Forces (SOF) operating close to the enemy line has become the norm in the military campaign of today and the foreseeable future. The fire support from naval surface combatants provides the most efficient and effective support to eliminate or soften the resistance. But the danger of fratricide (hurting own forces) or missing the target will hamper the success of those missions. NSFS is a highly sophisticated and coordinated action. While the gun crews perform the operation and firing of the gun weapon system (GWS), the mission planning and fire control functions are performed in the Command Information Center (CIC) of the surface combatant or at an even higher level of command and control. At the same time the forward observers reports the target information and the impact information of the gunfire so that correction can be made for rounds on target. All of those participants need effective training to achieve the desired level of proficiency.

To train and sustain the force readiness, periodic training exercises are indispensable. For training exercises, the deployment of the ship(s), forward observers, and the preparation of the live-fire facility are expensive and difficult. The wear and tear and attrition of weapon hardware also add to the total cost. A main consideration is the impact of the training facility on the environment and the surrounding area. One example is the Naval target range on Vieques

Island. The population expansion and urbanization resulted in the move of civilians closer to the test sites and target ranges. The anti-military movement and other political reasons make the live-fire range facility an easy target for protests. Any accident only adds more bad publicity to the already unpopular issue. Dealing with the pressure from various interest groups, governments around the world face the shortage and loss of training and live-fire facilities [1].

Modeling and simulation has provided for a limited capability for training. In several cases, such as small arms training, simulated firing can be achieved in specially built facilities. Large weapon systems can also take advantage of those built-in trainers to perform limited training and exercises. However, there still exists no systematic and low cost solution for the full-scale problem.

APPROACH

A possible solution to this problem is borrowed from electronic arcade games. That is to create a "virtual" environment and insert appropriate hardware/software that can emulate the operation of the weapon system or systems into this virtual environment so that the operators can perform either live-fire or simulated live-fire of the weapon systems in an open-ocean environment. This approach seems to be easy but many issues have to be resolved before a satisfactory result can be achieved.

First of all, the simulator for a weapon system must have enough sophistication to emulate the functions and responses of the weapon system. Secondly, the fidelity of the simulator and the virtual environment has to be of high quality so that the operators can experience "real" feeling from the virtual environment. Thirdly, the simulator has to be compact and robust, and should require minimal training and maintenance. Also, the simulator has to provide convenience and saving. Above all, the simulator/trainer has to be easily upgradeable to accommodate changes in the weapon systems or war fighting doctrine.

For NSFS application, an appropriate simulator/trainer faces many technical challenges. At a minimum, a typical NSFS fire mission involves operators from the Command Information Centre (CIC) for fire control and mission generation, gun weapon system (gun crew) for operation of the gun and loader, and the forward observer (the spotters), to provide target data and report the impact of the rounds. The simulator would be required to interface with all of these areas. The approach of the Naval Virtual Target Range (NVTR) is to use the existing CIC and gun weapon system as integral parts of the trainer if the operation of the complete fire control and gun weapon system is required. When those elements are not available, the NVTR can emulate the functions of those "missing" pieces and still perform the training functions in complete simulation mode. The Gun Liaison Officer (GLO) or spotter is a significant part of the overall exercise. He views a display dedicated to producing near realistic views from the spotter's position to train the spotter to observe the impact of rounds and determine their effect. The NVTR allows the training and exercise of either live-fire or simulated fire in a near realistic environment.

SYSTEM DESCRIPTION

Overview

The NVTR consists of three major components, namely the System Controller, the Sensor Subsystem, and the Spotter Station (see Figure 1).

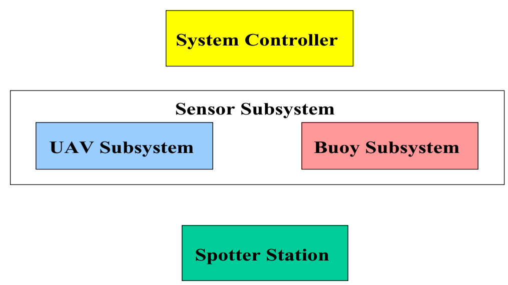

Figure 1. The NVTR is a modular constructed weapon training system

The System Controller performs the overall control functions of the NVTR. Those functions include initializing the system, providing various views (map view, "God's Eye" view, and instrumental view), operating and monitoring the operation of the system, and interfacing with other components of the NVTR and shipboard equipment. It has a processor, a database, at least two sets of transmitters/receivers, a Global Position System (GPS), several displays, and controllers (keyboard and computer mouse).

The Sensor Subsystem provides the sensor feedback to the System Controller. The Sensor Subsystem, at this moment, can be either an Unmanned Aerial Vehicle (UAV) Subsystem or a Buoy Subsystem. The UAV Subsystem uses one or several Unmanned Aerial Vehicles to scan the target area and report the impact points of the rounds. The Buoy Subsystem consists of several GPS sensor-equipped sonobuoys that are deployed around the target area and transmit the data about the impact of rounds back to the Control Station. Each platform of the Sensor Subsystems (UAV or buoy) has, in addition to the sensors, a transmitter and a GPS.

The Spotter Station provides the view from a specific position. The purpose of this is to train the spotters (Forward Observers and/or Naval Gun Fire Spot Team) how to spot the impact points and adjust future rounds onto the targets. The high fidelity display provides the spotter a near-realistic view for training. The hardware/software of the Spotter Station consists of a copy of the same database as the System Controller, a processor, a GPS, and a receiver to receive the data from the System Controller. The displays and "hand controllers" also emulate the functions and appearance of the Lightweight Laser Designator Rangefinder (LLDR) and Digital Automated Communications Terminal (DACT) of the Target Location Designation and Handoff System (TLDHS) used by those Forward Observers and Naval Gun Fire Spot Team.

In the Simulation mode, the NVTR may perform all the functions including the generation of the firing mission and firing order, the gun firing, the impact of the rounds on the water (as in the open-ocean environment), the sensing of the impact, the calculation, and display on the virtual target in a complete simulation mode. The NVTR may also perform in a coordinated manner with the CIC (fire mission and other fire control functions) and the gun weapon system (the launch of the rounds) for live-fire mode. The two modes of operation can be depicted as in Figure 2.

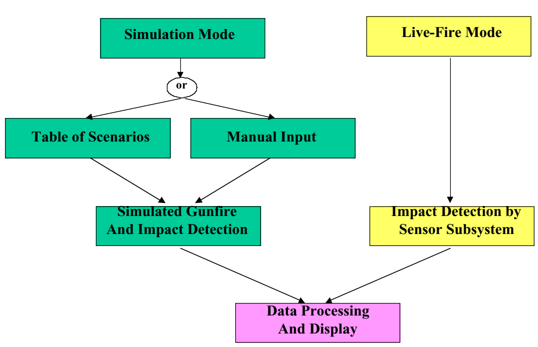

Figure 2. The NVTR has two modes of operation

The function of the Sensor Subsystem is to detect when where, and how a round impacts on the water. When the UAV Subsystem is used as the Sensor Subsystem, frame-by-frame images of the target area are sent back, and then a set of algorithms in the System Controller will detect "if there is an impact on the water." This is necessary to distinguish the splash of the rounds from reflection of objects, waves, sensor noises, and other factors. If an impact is detected, a second set of algorithms will determine the centroid of the impact. With the GPS data, position data, and the time stamp of the camera view, a third set of algorithms will compute the impact point on the water in the earth coordinates. When Sonobuoy Subsystem is used as the Sensor Subsystem, several sensor-equipped buoys will use triangulation to determine the impact point of the round.

Using the computed trajectory of the projectile round (a space curve), the impact point on the water (a point to fix the space curve), and the terrain database (a "mathematical" surface in the space), the processor in the Control Station can compute the impact point of the trajectory of the round on the virtual terrain (the intersection of the space curve with a surface). A predetermined software package will generate the "special effect" according to where the round "hit". The displays of the effect on the Control Station and the Spotter Station differ in that the display on the Control Station can be manipulated to show any view angle whereas the one on the Spotter Station is displayed according to the pre-determined view angle, distance, and location of the spotter to the target (impact point).

To simplify system construction, minimize the system cost, and speed-up the data processing, the communication within the components of the NVTR is kept to a minimum. Only essential alphanumerical data are transmitted between the Sensor Subsystem and System Controller and from the System Controller to the Spotter Station. Other than transferring video images from the UAV Subsystem to the System Controller, only simple numerical data is transferred between the System Controller and the Spotter Station. The graphics software and algorithms will generate identical "effects" of how the rounds performed in both the displays of the System Controller and the Spotter Station even though the view angles may be different.

Lab System Construction And Tests

A lab NVTR set-up has been designed, analysed, tested, and modified through a multi-phased development stage. The first phase of the NVTR development was the concept formulation and analysis. Interviews with NSFS users and people experienced in direct/indirect fire support and its associated training, discussions of their views have given insight on how a trainer could be functional. The developers have also paid visits to several training facilities to further understand the state-of-the-art and areas that need improvement. A rough order concept was the result from this effort.

The next phase was to refine and analyse the rough order concept. In this effort, the developers have defined the problems and identified potential approaches and requirements for the solutions. The developers performed literature research for available tools/hardware/software and special know-how. From those results the developers have formed a conceptual NVTR and started the detailed design, and, in parallel, performed system simulation using a combination of general-purpose computers and lab-constructed hardware/software.

From the study, the developers found out that to acquire the accurate location of the impact points on the water in a timely manner was the most important factor for the success of the NVTR development. State-of-the-art practices use different sensor systems that surround the target area and use "triangulation" to pinpoint the impact location. Existing systems mainly use fixed sensors to gather the data. This would limit the target area to a fixed location. The maintenance of those sensor platforms requires a special facility and the cost is high. To make this system versatile so that it could operate in any convenient location was the main objective of this development effort. This eliminates the requirement for a dedicated facility.

A lab test set-up was constructed using the SES™ (Simulation, Emulation, Stimulation) process [2] that has been developed by the United Defence. The SES™ process is originated from an electronics/software system integration process. This process, after having been successfully used for the integration of the first all-digital combat ground vehicle system, has been modified and improved and used on several large-scale system integration projects and programs.

The first step of the process was to build a modular-constructed computer simulation model. Initially much of the simulation model will be low fidelity (i.e., simple). This is due to a combination of lack of understanding of the system, cost saving, and "getting information fast." But special emphasis will be in the area of interfaces among those subsystems and components. High fidelity interfaces and communications among those simulation model components are essential for the success of this process. This is the simulation stage. The second step of the process is to construct a hybrid software/hardware infrastructure for the communication and interfaces among those simulated components. The communication and interfaces are constructed using commercial-off-the-shelf (COTS) components or existing lab equipment. Special software components were also constructed so that one simulation module would communicate with another simulated component following the same communication protocol, having the same physical characteristics (e.g., same voltage level, same time responses, same number of bits, etc.,), and using the same device drivers when those are needed. This is called the emulation stage. At the end of this stage, basically, the developers have constructed a hybrid lab system that will "mimic" the simulated system in many aspects. This is an "emulation system". After this stage, each simulation module of the emulation system can be replaced easily by an improved (with higher fidelity) simulation module, or a functional equivalent hardware/software. When hardware/software prototypes of those system components become available, one at a time, the simulation model components would be replaced by the improved simulation model components or prototype components. The third stage is to use either computer simulation models or other lab test equipment to stimulate the constantly improved emulation system. This is the stimulation stage. The SES™ process may go through these three stages in sequence or back and forth between these stages until a completed lab system is achieved. Using the SES™ will force developers to pay special emphasis on the issues about interfaces early. This will clear many issues associated with system integration and test since the beginning of the process. Using the SES™ process has many other advantages; the developer will have a better understanding of the system throughout the development stage by acquiring constant improvement of the system simulation and emulation. Most hidden issues and problems would surface early. This would provide the developers with ample time and a suitable environment to try various solution candidates in search of the optimal solution [3].

In the lab test set-up design, the System Controller overlays the designated target information (terrain database, 3-D target area data, target type, etc.) onto a predetermined coordinate system. The same data is also loaded in the Spotter Station for display. In addition to that data, a viewing angle and simulated position of the spotter are also registered into the processor unit of the Spotter Station for the generation of an appropriate view to emulate a scenario. The synchronization of the time and displays between the System Controller and the Spotter Station is very important. The communication between these two stations is kept minimal to expedite the generation of "real-time" display.

Each component and subsystem of the lab test set-up was built using COTS components. The engineers built these functionally equivalent units (FEU) of parts and subsystem of the NVTR according to the corresponding simulation models. When the performance of these FEUs differ from the simulation results, then either these FEUs or simulation models have to be modified so that consistency can be achieved. The next step was to create a hybrid NVTR lab system by using a combination of simulation models and FEUs to emulate the complete NVTR system. This Lab Test Set-up was then used for the performing of various system tests.

Due to the complexity of naval gunfire, it was not possible to re-create the test environment using these limited resources for a complete system test. Instead, the engineers used innovative methods to overcome this problem. Since the purpose of the sensor system for the NVTR is to detect the impact point of the projectile on the water, when a "real" gun was not available, various improvised methods and surrogate items were used. The engineers dropped sizable rocks and boulders into the water to test the sensor system and the detection algorithms (see Figure 3). Later, videotapes of gun test were used to confirm the feasibility of those algorithms. When the UAV was not available, a radio-controlled model plane and model helicopter with appropriate payload capability were used to test the FEU of sensor system operation in fly-out tests (see Figure 4). A complete test over water using a real naval gun weapon system will be needed to perform a complete evaluation of the NVTR System.

The developers have used standard general-purpose computers as the processors and displays in both System Controller and Spotter Stations. In the early days, high-end Silicon Graphics machines based on a UNIX operating system were used. Later, ruggidized personal computers running on Microsoft Windows Operating System have replaced all those UNIX-based computers. This approach cannot only lower the system cost, it can also achieve a ruggidized and modular constructed system using only COTS components. All cameras, image and data processing boards, and other sensory/communication components are COTS items.

The developers have tested different image processing algorithms. An improved Robert Operator [4, 5] yielded the fastest response for image detection, and hence has been chosen for the initial image processing. After the initial image processing to extract the raw data, a series of decision algorithms will make the detection and decision autonomously. The developers have also tested various standard digital filtering techniques and selected those, which yield the fastest responses for our applications. For those computation intensive algorithms, other than calculating the point of intersection of the projectile trajectory with the imaginary terrain, the developers have used only "closed-form" solutions to avoid any possible "infinite loop" in number crunching. The developers used only a single iteration algorithm for the computation of the impact point on the imaginary terrain. From the analyses and tests, this algorithm would converge to the mathematical solution within two to three iterations.

The developers selected C++ as the programming language to produce the custom-made software code in the NVTR. Those include various algorithms, few device drivers, communication software, decision-making algorithms, etc. The developers used COTS graphics and animation software for the displays. In addition to the monitors of those general-purpose computers, the developers have tested the use of a Head Mounted Display for the Spotter Station display and decided it did not provide any measurable advantage compared with the computer monitors.

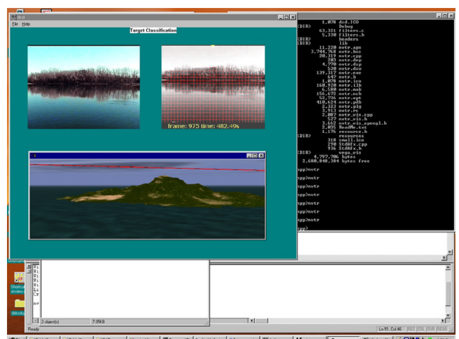

Figure 3. The test results confirmed the suitability of the image-processing algorithm

Figure 4. A surrogate UAV was equipped with cameras, GPS, and communication systems for testing

DISCUSSION

From the development of the lab demonstrated NVTR, discussions with personnel who were responsible for the maintenance of existing training facilities, and the information gathered from the users of GWS, the developers have learned the following lessons:

Time Response

To speed up the time response, the developers used two identical copies of animation software that reside in both the Spotter Station and System Controller. Only alphanumerical data should be transferred between the System Controller and the Spotter Station. From the past experience, the developers have found that a human operator can detect a time delay of 300 milliseconds or more [6]. It would be impossible to achieve real-time response using acoustic sensors. The use of hydrophones on the buoys as the Sensor Subsystem would result in substantial time delays. Sound travels at a speed between 3700 to 4700 feet per second in water [7]. The closer deployment of the buoys in the impact area may pose the danger of buoys being destroyed by the projectile. The use of cameras on the UAV can speed up the sensor detection (light travels at a speed of 2.99792×10^8 meter per second in the air [8]), but the precision of all the sensors on the UAV would be very important to acquire a relatively accurate result. The use of a UAV Subsystem may have another advantage, in that it has the potential to detect rounds impacting on land, as well as to detect airburst, cargo-type rounds, and illumination rounds. The results will be reported in the future.

Accuracy/Precision

The accuracy and precision of the NVTR depends on many factors. Those include the sensor accuracy, sensor location, precision of alignment, computation errors, and calibration error, among others. The closer the sensors are located to the impact point, the more accurate they will be. But, again, this will associate them with the risk of damage by the projectiles.

Sensor Deployment and Recovery

Since the NVTR lab test unit has been tested only in a limited and controlled manner, the developers could not report the results of the performance of the NVTR in extreme conditions. However, the developers know that there are several issues associated with the sensor deployment and recovery. In the open sea, the deployment of the buoys could be accomplished either by helicopter, small craft, or own ship. The developers have studied the use of low cost "expendable" buoys and have determined that they would be a more appropriate solution (see Figure 5). The price of electro-optics and other electronics has dropped substantially, and the developers are anticipating that the cost of these buoys will be less than $1000 each. The developers will further investigate the potential of using different sensor systems on the buoys. The results shall be reported in a paper at a later date. The use of the UAV will present different problems and issues. Small UAVs have limited sustain time in the air. Winds will also hamper the performance of the UAV. A potential low cost UAV subsystem is a gun-launched UAV (GLUAV, see Figure 6). This GLUAV may be launched from the same gun weapon system that will be tested or used for the virtual exercise. The low cost of construction and maintenance and the immediate arrival at the target area allow the GLUAV system to be expendable and not require a long operational sustain time. Using the GLUAV can simplify the sensor subsystem deployment and recovery problem.

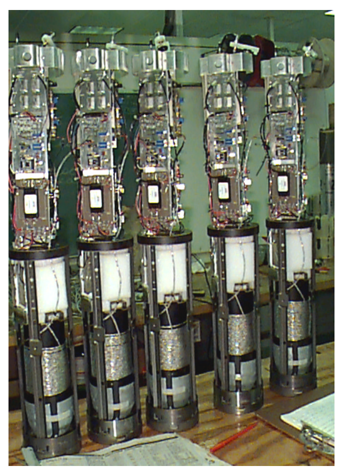

Figure 5. These low-cost buoys can perform the detection function as well as their high-cost counterpart

Figure 6. This gun-launched UAV might overcome the low sustain time problem associated with small UAVs by reaching the observation area fast

Maintenance and Product Support

The NVTR can have up to four major subsystems (using both the Buoy Subsystem and UAV Subsystem as the Sensor Subsystem). The System Controller and the Spotter Station can co-exist with any other displays or control systems. There is no maintenance requirement other than the power of the computer equipment and transmitter/receiver. The modular construction of the NVTR allows the system to be upgraded or modified by changing the database or using different algorithms. Other than the power train of the UAV and the battery pack for the electronics, the Buoy Subsystem and the UAV Subsystem will not need any regular maintenance.

Airburst and Cargo Rounds

The detection of airburst and cargo rounds will create a more difficult challenge for the system. The height of the airburst or the location of the round starting dispensing sub munitions is no longer on the sea surface (In our algorithm, at sea level, mathematically in (x, y, z) coordinate, z = 0. And this boundary condition allows the use of a single UAV to locate the impact position of the round on water.). Determining the location of an airburst or the location of a projectile as it starts dispensing sub munitions requires different algorithms for automated detection and computation. For these kinds of rounds, according to our study, a UAV Subsystem would be a preferred choice as sensor subsystem. Multiple-UAVs will be needed to locate the exact positions of airburst and submunition dispensing. Acoustic sensors may not be able to detect the dispensing of subminitions, and hence, other devices such as radar or camera systems will be the desired sensory systems.

Naval Surface Warfare Application

The NVTR was developed based on the training requirements for NSFS. Its primary function can be easily modified for use in the Naval Surface Warfare (NSUW) training application. The NVTR can generate virtual surface targets and perform needed gunfire exercises for NSUW.

Pathfoward

The whole idea about the NVTR was based on the search for a solution for the gun weapon system live-fire training problem encountered by the US Navy. The use of the SES™ Process may have generated a quick and suitable solution to the problem. Many new ideas also were generated while using the SES™ Process during the development of the NVTR prototype. For example, the use of an easily launched (from the gun weapon system or hand-launched) UAV by the existing gun crew as the sensor platform may provide a new means for fire support mission, i.e., the use of an unmanned, remotely operated sensor platform for indirect fire operation and battlefield assessment without exposing human operator (gun spotter) in harms way. This approach will not add any burden for extra personnel.

The modular constructed NVTR System allows the system to be either a stand-alone system or integrated to the existing gun weapon system. The SES™ Process makes the use of modelling and simulation to fulfil the functions of most "missing linkages" in the NVTR System by inserting appropriate simulation models into the system infrastructure. This approach demonstrated one more time how powerful the use of modelling and simulation can be.

The selection of an HLA/DIS (High Level Architecture/Distributed Interactive Simulation) [9, 10] compatible infrastructure for the NVTR System architecture makes the linking of the NVTR to another HLA/DIS compatible simulation easy. Using this, force level simulation can be achieved by linking distributed elements into an integrated system to perform complicated simulation. This approach will not only generate new opportunities for NVTR-like system but also enable the commanders and mission planners to use a combination of hybrid real and simulated weapon systems remotely located at different sites for force level exercises and trainings.

CONCLUSION

This paper reported the development of a naval virtual target range and weapon system trainer using a combination of computer simulation, sensory systems, automated algorithms, and other off-the-shelf components. Computer simulation basically fulfils the missing elements in a full-scale live-fire scenario, namely the target(s), the terrain, and the special effects that are associated with live-fire. Modelling and Simulation also can play the complete role of gun weapon system firing exercise when there is no live-fire.

The fidelity of this NVTR depends heavily on the type of sensor system it uses. The hydrophone sensor has substantial time delay due to the measurement of the sound that travels at a slower speed compared with the camera system that measures at speed of light. The accuracy, again, primarily depends on the type, precision, and the location of the sensor subsystem.

In order to make the NVTR system more flexible for different scenarios and application, the developers have used open system architecture following the SES™ process [2, 3] so that a modified unit can replace each element of the system with the least amount of effort. This approach allows the simulated components to be replaced by functionally equivalent hardware, software or simulation models. As long as the interfaces between those components are well defined and constructed correctly, the overall function and performance of the system shall be transparent to the system operator. The development of the NVTR has demonstrated again that using powerful modelling and simulation tools and techniques minimize much of the difference between "virtual" objects and "real" objects in many applications.

The developers have constructed a lab set-up of an NVTR system and they have performed several tests using a combination of COTS-constructed equipment and surrogate systems. The results were favourable and confirmed the results from the computer simulation. However, live-fire tests are needed to validate this NVTR and the developers are working with GWS organizations for the performing of live-firing tests. The test results will be reported in a later date.

ACKNOWLEDGEMENT

The authors wish to thank many of their coworkers, without whose hard work the success of this project would not have been possible, these include Mr. Chris Holmes, Mr. Jeff Wolff, Mr. Ron Schwinn, and Mr. William Wegerer. The authors wish to give special thanks to Mr. William Allshouse for supporting the surrogate fly out tests. The authors also wish to thank United Defense management for their support and encouragement to develop this project.

REFERENCES

[1] *US to End Vieques Bombing in 2003*, (2001, June 14), CNN Report

[2] Huang P., Kar P., Kennedy A., Kato H., System Integration Laboratory - *A New Approach to Software/Electronics System Integration,* (1996, July), Sixth Annual International Symposium, International Council on Systems Engineering, Boston

[3] Huang P., Kar P., Fandrich C., *Using Modeling and Simulation for Rapid Prototyping and System Integration,* (1997, October), 1997 IEEE International Conference on Systems, Man and Cybernetics, Orlando, Florida

[4] Castleman K.R., *Digital Image Processing*, (1995, August), Prentice Hall

[5] Jensen J. R. R., *Remote Sensing*, (2000, January), Prentice Hall PTR

[6] Jordan, W., *No Second Place Winner,* (1965), W. H. Jordan

[7] Wilkes R.J., *Speed of Sound in Water*, (1997, November 5), JASA

[8] Marion J. B. and Hornyak W. F., *Physics for Science and Engineering*, (1982), Saunders College Publishing

[9] *DoD Directive 5000.59: Modeling and Simulation (M&S) Management Definition*, (1994, January 4)

[10] Gagnon, F., Simon, E., and P. Howells, *On the Development of a Generic Interface for HLA and DIS Simulations*, (1998), Proceedings of the Second International Workshop on Distributed Interactive Simulation and Real-Time Applications

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