UNDERWATER WARFARE SIMULATION IN DISTRIBUTED SYSTEM WITH DELTA3D

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ABSTRACT
Forecasting performances of the weapon systems is very difficult to estimate as mathematical equations because there are many variables to consider. Modeling and simulation techniques have raised the optimal solution that can evaluate development and deployment of weapon systems. Simulation purposes are a decisive factor to design simulation systems, yet to develop a simulator for every single purpose is costly, un-swift, and inflexible. A distributed simulation system allows large-scaled simulations with economical input resources by linkages of existing simulators to the system, and it is also flexible and rapid to redesign the system for other purposes. This research implements underwater warfare simulation using Delta3D simulation game engine, originally designed for the military simulations, in a distributed system, and the simulation system interchanges environmental data due to underwater operations are mostly affected by environmental situations. This research adopts SEDRIS for environmental data and HLA/RTI for the distributed system.

Keywords: Delta 3D, HLA/RTI, SEDRIS, Underwater warfare

1. INTRODUCTION

Recently, military modeling and simulation (M&S) has remarkably grown in its importance and it is inevitable in the planning and operation of national defense strategies and war fighting efforts. The phenomenon is caused by the complexity of modern weapon systems which are highly increased by the development of the scientific technologies in comparison with weapons` history. The battle field of modern warfare is not the equal to the simple concept of the past, but it rather involves many complicated resources, such as network-centric warfare (NCW) concept (Lee and Wang, 2008). Therefore, modeling these high technologic weapon systems and battle field is not a simple question to gain the answer from mathematical equations. M&S is necessary to achieve cost-effectiveness weapon systems development, to examine the synergism of various weapon systems, and experiment environmental effects of the battle field to weapon systems, except for traditional purposes, such as training (Park Kwon Seong and Pyun, 2010).

Distributed simulation system helps to achieve various M&S objectives by integration of legacy simulators because existing simulation systems historically have been confined to single, isolated developed for single purpose. However, efforts to build new simulation system include large-scaled and complex modern warfare resources require tremendous time, cost, and human-power. Thus, distributed simulation system is in demand to obtain systems for various purposes with combination a multitude of individual simulations of existing simulators into larger simulations (ADSO, 2004). US Department of Defense (DoD) founded Defense Modeling and Simulation Office (DMSO) as an affiliated organization. The DMSO was renamed the Modeling and Simulation Coordination Office (M&SCO) in 2007. M&SCO has been leading DoD M&S standardization and empowering M&S capabilities to support the full spectrum of military activities and operations. M&SCO developed and released the IEEE 1516 High Level Architecture (HLA) standard which is distributed simulation architecture designed to facilitate interoperability and promote software reusability (M&SCO, 2012). Run-Time Infrastructure (RTI) is implementation of HLA and fulfillment of objectives of distributed simulation system.

In HLA/RTI systems and any military M&S applications, the environmental data are crucial in the depiction of the synthetic battle field situations, but the proprietary nature of various environmental data formats that reside in each simulation platform. It is a great impediment for the interoperability. The solution to this problem is the standard intermediate data format that permits the interchange of unified data between heterogeneous simulators. The Synthetic Environmental Data Representation and Interchange Specification (SEDRIS) provide a standard interchange mechanism for various environmental data. It increases the data reuse across diverse simulation platforms. SEDRIS addresses and represents all the aspects of synthetic environment, such as terrain, ocean, atmosphere, and space. SEDRIS supports a timely and authoritative representation of synthetic environment (Foley Mamaghani and Birkel, 1998). It bears the consecutive efforts that are dictated by the DoD M&S Master Plan (DMSO, 1995).

Proceedings of the International Defense and Homeland Security Simulation Workshop 2012
ISBN 978-88-97999-08-9; Bruzzone, Buck, Longo, Sokolowski and Sottilare Eds.

The representation of the environment to the synthetic battlefield is a critical factor in the simulation of naval warfare. This is multidimensional and it encompasses air, sea surface, sub-surface (underwater), land, space, and time. The survival and combat effectiveness of the naval force are considerably affected by the environmental factors of those dimensions. Command and control of naval warfare unifies ships, submarines, aircraft, and ground units. Thus, naval warfare system has a full range of environmental factors to represent the battle field. The underwater warfare is a part of naval warfare, and it inherits characteristics of a battle field of naval warfare. The general operation of underwater warfare is structured by using three forces, namely, submarines, surface ships, and air units. Figure 1 describes the concept of the future NCW-based anti-submarine operation system. It shows the integration of the combat units to accomplish a given mission (Mundy and Kelso, 1994).

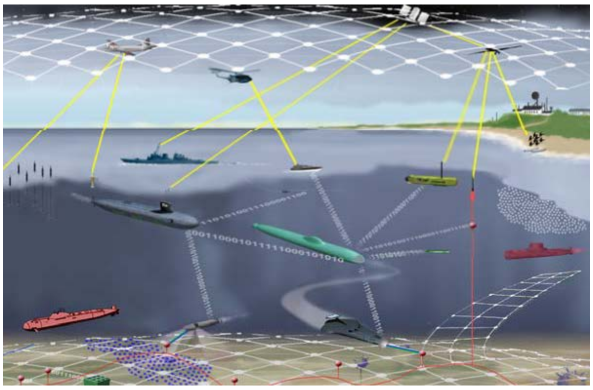


Figure 1: Anti-submarine Warfare Concept based on Network-Centric Warfare

Radar (an acronym for RAdio Detecting And Ranging) is an object-detection system that uses radio waves which do not work in underwater environment, as radio waves hardly penetrate through large volumes of water. Thus, the mean, instead of the radar, is sonar (an acronym for SOund Navigation And Ranging) and it detects objects that are under the sea by using sound propagation to identify objects, navigate, and communicate with other units under the sea. All submarines have sonar systems to navigate underwater, detect enemy, and so on. A submarine force has high capability to conceal itself, and it usually sails deep underwater. The submarine force can detect the surface ship force much easier compared to that of the surface ship force which detects the submarine force. It is precisely difficult to detect a submarine force to the surface ship force by itself, due to the environmental characteristics of underwater regarding sound propagation efficiency. Even if some surface ships have sonar systems for the anti-submarine operation, they load anti-submarine helicopter that has equipped dipping sonar to enhance their limited anti-submarine capability. The anti-submarine helicopter is one of the air force, and another is the anti-submarine plane. The dipping sonar hangs on the helicopter with a cable and it is dropped into underwater. The anti-submarine plane recognizes the electromagnetic waves of the submarines in the deep sea of flying area. The main assault weapon is the torpedo. It also has sonar system to navigate and detect the target (Brady and McCormick, 2008).

By considering of previous description of underwater warfare, the sonar is the most important system of the warfare. There are two types of sonars: passive sonar and active sonar. Passive sonar system is a sound-receiving system that uses hydrophones (underwater microphones) that receive, amplify, and process underwater sounds. Active sonar system emits pulses of sound waves that travel through the water, reflect off objects, and return to receiver. It can be the most effective means available for locating objects underwater. Active sonar system can be used to determine the range, distance and movement of an object. However, the performance of both types of sonar system depends on the environment and the equipped devices; receiver or emitter. To enhance the performance of the devices is limited, because the size of sonar has to be large enough to emit highly powered sound waves. Therefore, underwater operations are dependent on the environment in usual. The environment features affecting sonar operation are mostly sound speed, thermocline, and refraction of sound waves, and the three factors disturb sonar detection. For example, a ship equipped sonar system emits a sound wave, but the sound wave do not meet enemy submarine in thermocline area. Salinity and temperature are decisive environmental factors of those three features, yet the factors are various in the environment of underwater. Due to the variations in sound speed, the possibility to detect underwater objects using sonar is became different by the environmental factors. Consequently, it is now clear that the environment is the most important factor of the underwater warfare.

This paper explains constructing the underwater warfare simulation system, which needs environmental data to reflect environmental effects, based on the synthetic battlefield. This paper also provides an example implemented by Delta3D simulation game engine. The synthetic battlefield is constructed in SEDRIS, and it is supplied to the simulation from HLA/RTI based distributed system.

2. TECHNICAL APPROACH

The battlefield of the underwater warfare is able to model as a time-dependent three-dimensional grid space. It denotes an environment that is structured by time dimension, horizontal dimensions (i.e. latitude and longitude), and vertical dimensions (i.e. altitude and water depth). Figure 2 describes the structure, and it shows a three-dimensional grid space. The time-dependent denotes several of the structures along a lapse of the time dimension, and the time dimension identifies a data collection period. The structure generates cells that are defined by grid axes, and the each cell contains numerical values of the environmental properties.

In order to construct the synthetic battlefield for the underwater warfare, SEDRIS is adopted. SEDRIS has two core objectives. One is to represent environmental data, and the other is to interchange environmental data sets.

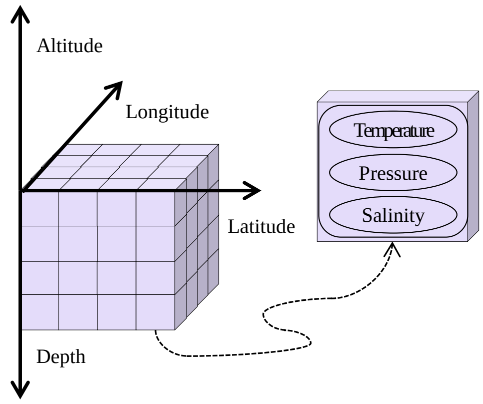
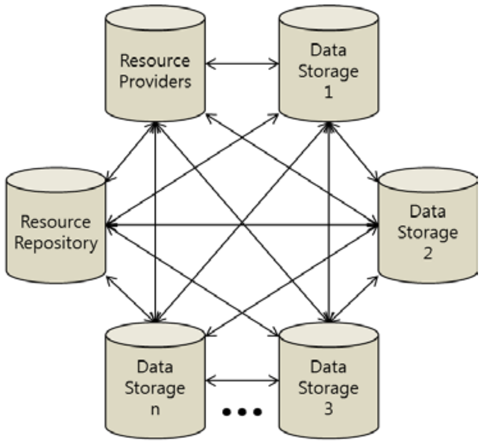


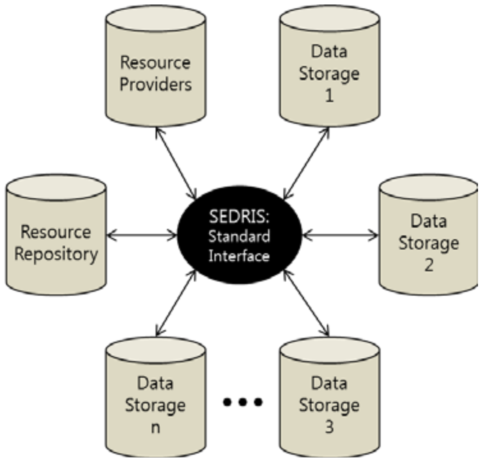
Figure 2: Environment Structure for Atmosphere/Ocean

In order to obtain the objectives, SEDRIS is composed of five components: Data Representation Model (DRM), Environmental Data Coding Specification (EDCS), Spatial Reference Model (SRM), SEDRIS Application Program Interface (API), and SEDRIS Transmittal Format (STF). DRM, EDCS, and SRM are core parts of SEDRIS, and STF is a product which is produced by combination of DRM, EDCS, and SRM. STF is also SEDRIS data file format which has information for describing environment, and this achieves the first objective of SEDRIS. SEDRIS API allows developers helping to access and generate STF with DRM, EDCS, and SRM. This makes SEDRIS achieve the second objective by data conversion between STF and others. There are SEDRIS API and STF to access and use SEDRIS core parts. SEDRIS API is constituted by DRM API, EDCS API, SRM API, and Transmittal Access API that is to make STF use all other APIs, and available on SEDRIS homepage. There are also many tools are free to open STF such as Focus, Model Viewer, Depth, Syntax checker, and Rule checker. SEDRIS can attain the interoperability in distributed simulation system as the standard format. Figure 3-(a) describes the point-to-point unique conversions between the data formats. This method requires converters for every data format, which needs 2 x (N-1)! (N: the number of data formats) converters. Therefore, this method can be very expensive and time consuming. Figure 3-(b) outlines the data interchange with SEDRIS as a standard interface with a common data model. This method can substantially reduce the conversion costs and related errors with the increased level of data reusability. As a standard interface, SEDRIS assumes a centralized intermediary between numerous environmental data formats (Welch, 1998).

The battlefield information is not a constant element, or rather changeable by scenarios that specify the place to take. It is also heavy and large data to manage in a battle simulator. Hence, it needs to be managed by an application, which is developed for environmental data only. HLA/RTI based distributed system is an appropriate approach to supply environmental data to the simulator.



(a) One-to-One



(b) Standard Interface

Figure 3: Data Interchange Methods

3. IMPLEMENTATION

Sonar is a technique that applies sound propagation to navigate, communicate with, and detect to other objects in underwater environment. A submarine has several sonar systems along with various purposes, for example, exploring the underwater ground, reconnaissance and detecting objects, identifying detected objects and tracing enemies, using passive and active sonar systems. The sonar operations are affected by variations in sound speed, particularly in the vertical plane. Several factors that affect performances of the sonar operations are also dependent upon the sound speed. Hence, modeling synthetic environment for underwater warfare simulation is devised to calculate the sound speed. There are two simple equations to calculate the speed of sound in seawater defined by Mackenzie (1981) and Coppens (1981).

Proceedings of the International Defense and Homeland Security Simulation Workshop 2012
ISBN 978-88-97999-08-9; Bruzzone, Buck, Longo, Sokolowski and Sottilare Eds.

The equation (1) for the speed of sound in seawater is given by Mackenzie.

Function Input:
T = Temperature in Degrees Celsius
S = Salinity in Parts per thousand
D = Depth in Meters

$$c(D,S,T) = 1448.96 + 4.591T - 5.304 \times 10^{-2}T^2 + 2.374 \times 10^{-4}T^3 + 1.340 (S-35) + 1.630 \times 10^{-2}D + 1.675 \times 10^{-7}D^2 - 1.025 \times 10^{-2}T(S - 35) - 7.139 \times 10^{-13}TD^3 \quad (1)$$

The equation (2 and 3) for the speed of sound in seawater is given by Coppens.

Function Input:
t = T/10 where T = Temperature in Degrees Celsius
S = Salinity in Parts per thousand
D = Depth in Kilometers

$$c(D,S,t) = c(0,S,t) + (16.23 + 0.253t)D + (0.213-0.1t)D^2 + [0.016 + 0.0002(S-35)](S - 35)tD \quad (2)$$

$$c(0,S,t) = 1449.05 + 45.7t - 5.21t^2 + 0.23t^3 + (1.333 - 0.126t + 0.009t^2)(S - 35) \quad (3)$$

Both equations are simple and old equations, but it is yet reliable and effective equations to derive the sound speed using environmental data. Along the requirements of two equations, temperature and salinity are the most important factors to know the sound speed. Therefore, the synthetic battlefield model for underwater warfare has to contain those two factors in each cell that are structured by three spatial-dimensions.

In HLA/RTI based distributed simulation system, the environment federate manages the environmental data, and it provides environmental data ranged by the request from the battle simulator. The battle simulator publishes spatial extent of the synthetic battlefield and subscribes the environmental data. The battle simulator calculates the sound speed using the subscribed environmental data, salinity and temperature. The calculated results are used to obtain the probabilities of the detection among the battle agents. The sonar operations are able to be modeled using the speed of sound propagation by sound transmission models, such as Range-dependent Acoustic Model (RAM) and Bellhop. The battle simulator includes these models to decide whether a submarine detects the enemy or not. Battle agents are allowed recognizing other agents by the battle simulator.

The underwater warfare simulation system, which is mentioned above, was implemented using Delta3D along a simple scenario. The scenario is an engagement between two submarines: A and B submarines. A submarine moves on patrol some area, and it keeps search to find enemies using its sonar system. B submarine goes from start point to the area that is guarded by A. A is assumed that it launches a torpedo to enemy submarine, if it had an enemy in sight. Even if B was navigating in the searchable perimeter of the sonar system of A, it is possible that A cannot realize the existence of B by the environmental effects.

Delta3D includes the openness of the source code, the flexible interface using various APIs, and the three-dimensional graphical simulation of combat entities (McDowell, 2006). For instance, its library contains basic infrastructure, and a unification layer, and in-between, includes graphics, geospatial data handling, character animation, GUI, audio, physics, networking, input handling, configuration system, unit testing, scripting, and additional miscellaneous features. Delta3D is sufficient tool to develop simulations for underwater warfare. The example was constructed using the C++ language. The pictures of Figure 4-7 are acquired from Delta3D visualization of the battle simulator during the underwater warfare simulation in HLA/RTI system.

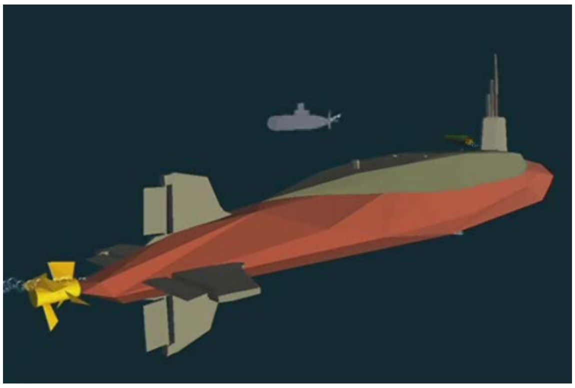


Figure 4: Submarine A Recognizes Submarine B

Figure 5: Submarine A Launches a Torpedo to B

Figure 6: The torpedo Traces Submarine B

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Figure 7: Submarine B is Torpedoed by A

4. SUMMARY

Military M&S provides lots of benefits to achieve objectives of future warfare paradigm. M&S allows experiments of the new weapon system, before investing on the resources. So, we can find out the problems and modify in advance. It is an appropriate approach to develop a new weapon system effectively for unexpectable and changeable future battlefield. We are able to acquire new weapon system with minimized wastes of time, costs, and efforts by applying M&S. M&S brings the benefits, however, engineers must keep watch on the result of simulation because the result could contain unreliable or improper conclusions. It is caused by that decisive factors of the simulation had not reflected to fulfill the purposes of the simulation. In the underwater warfare, the underwater environment is the most important factor to simulate sonar operations. Therefore, modeling the synthetic battlefield of the underwater is one of necessaries to construct the technically reliable underwater warfare simulation system.

Environmental data usually include large amount of numerical data and the data are required to be reused. Therefore, handling the environmental data by the battle simulator is not an efficient approach to build simulation systems. There are demands of an application to manage the environmental data. Applying distributed simulation system allows engineers to link several different applications. Thus, engineers are able to build the underwater warfare simulation system that separates environmental data and a simulator. In the future goal, the simulation system will be constructed on the more precise sonar operation model.

ACKNOWLEDGMENTS

This work was supported by the Defense Acquisition Program Administration (DAPA) and the Agency for Defense Development (ADD) under the Contract No. UD100009DD (DAPA), UD110006MD & UD110071JD (ADD). This paper was also completed with Ajou University Research Fellowship of 2011. The authors wish to express sincere gratitude for the financial support.

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