Autonomous Littoral Warfare Systems Evaluator – Engineering Simulation (ALWSE-ES)

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ABSTRACT

Performing surveillance, reconnaissance, mapping, reacquisition, identification, and neutralization of mines in the littoral environment is a very complex and difficult problem. The natural environment of this area is extremely dynamic and energetic, creating a formidable challenge for any appointed system.

Evaluating system performance and interoperability are also very difficult in this environment. The complex nature of environmental interactions requires the use of systems that rely increasingly on complex tactics, high-resolution peripheral components, and sophisticated processing algorithms. In addition, the availability and flexibility of autonomous platforms have resulted in thousands of available concept permutations addressing missions in the littorals. To evaluate the effectiveness of these concepts in an orderly, structured, and consistent way requires the use of an effective engineering-simulation based analysis approach.

CSS is currently developing a high fidelity, engineering level simulation tool named the Autonomous Littoral Warfare Systems Evaluator – Engineering Simulation (ALWSE-ES, pronounced "always", sometimes referred to as "E-S"). ALWSE-ES is closely related to the higher level, stochastic tool, ALWSE-MC and will serve as a foundational tool supporting an overall systems engineering toolset. ALWSE-ES allows the detailed characterization of environmental effects on systems under test, providing a synthetic environment in which to evaluate an engineering concept or design. This paper details the approach and implementation of ALWSE-ES.

The Autonomous Littoral Warfare Systems Evaluator – Engineering Simulation (ALWSE-ES) is being developed in support of the Very Shallow Water / Surf Zone Mine Countermeasures (VSW/SZ MCM) Reconnaissance Program, and is located at NAVSEA/Coastal Systems Station. The program sponsor is the Office of Naval Research (ONR) Code 3210E, Dr. Tom Swean.

BACKGROUND

A primary goal of the current VSW/SZ technology development programs is to ensure the timely and reliable delivery of resources in support of new operational concepts such as Operational Maneuver From the Sea (OMFTS) and Ship to Objective Maneuver (STOM) while reducing the risk to personnel and materiel. These technologies will carry the responsibility of providing an operationally safe path from seaward areas to the on-shore objective(s). Maneuvering and staging areas/lanes of passage must be verifiably cleared of threats that may impede the flow of personnel and resources. Current methods and technologies employed are quite time consuming and impose significant risk levels. New and innovative technologies are under development and will be employed to both increase operational capability and reduce operational risk.

Performing surveillance, reconnaissance, mapping, reacquisition, identification, and neutralization missions in the littoral environments is a very complex and difficult problem. The natural environment of this area is extremely dynamic and energetic, creating a formidable challenge for any appointed system. Evaluating system performance and interoperability are also very difficult in this environment. The complex nature of environmental interactions requires the use of systems that rely increasingly on complex tactics, high-resolution peripheral components, and sophisticated processing algorithms. In addition, the availability and flexibility of autonomous platforms have resulted in thousands of available concept permutations addressing various missions in the littorals. To evaluate the effectiveness of these concepts in an orderly, structured, and consistent way requires the use of an effective engineering-simulation based analysis approach.

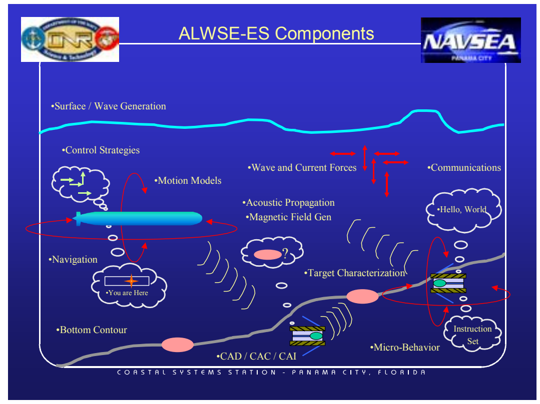

Figure 1
Environmental Situation

ALWSE-ES is a simulation designed to evaluate a complex system of systems operating together in the VSW/SZ regions. Figure 1, Environmental Situation depicts elements of the littoral environment in which VSW/SZ systems will operate.

Systems, moving along the ocean floor, in the volume, or on the surface will be required to navigate waypoints in spite of an unforgiving environment. They may have to move through seaweed, mud, silt, sand, or gravel. Obstacles, placed purposefully as deterrents or occurring naturally, must be countered as systems maneuver through the environment. Waves and currents batter the regions, at times violently. Conceived systems may require groups of similar systems acting in concert with their counterparts to achieve the coverage needed. System control systems not only have to govern a single vehicle's behavior, they have to control the entire group's behavior. Conditions within these regions may cause communication systems to perform poorly with low data rates and high error rates, and they may be subject to blackout conditions at times due to the formation of bubbles in the water caused by the surf. System sensors may include sonar, tactile, magnetic, and imaging. Once threats are located, the system may be required to report this information back to the assault forces, and possibly receive follow-on tasking. These inherit mission complexities will require ALWSE-ES to incorporate a large number of complex models in the simulation.

APPROACH

Conventional approaches to engineering and development, utilizing the "build-test-fix" paradigm, are not able to effectively isolate the performance parameters. This limits the ability of the developer to accurately tune designs or prototypes. In addition, the nature of the littoral environment simply will not allow reliable, repeatable tests due to its dynamic nature.

CSS is currently developing ALWSE-ES to answer the need for a high fidelity engineering level simulation tool to support the acquisition of the next generation of systems operating in the VSW/SZ region. ALWSE-ES is a physics-based, high fidelity engineering level simulation of the systems and environments of the littorals. ALWSE-ES allows the detailed characterization of environmental effects on systems under test, providing a synthetic environment in which to evaluate an engineering concept or design.

The implementation of ES is categorized into two main components: the simulation engine and supporting models. The simulation engine is responsible for the administration and execution aspects such as time advancement, participant tracking, data collection, performance monitoring, and data visualization. Supporting models are those resources that characterize the component or aspect of the environment. It is the marriage of the simulation engine and supporting models that provide a seamless representation of the environment and systems under test.

Modeling

Developing a simulation of the littoral systems and environment requires a teaming approach, with each team member providing access to and support for its particular area of expertise. The Coastal Systems Station (CSS) is solving this problem by focusing on the joint development and integration of the required models, using existing DOD and Navy standards for interfacing and interoperability.

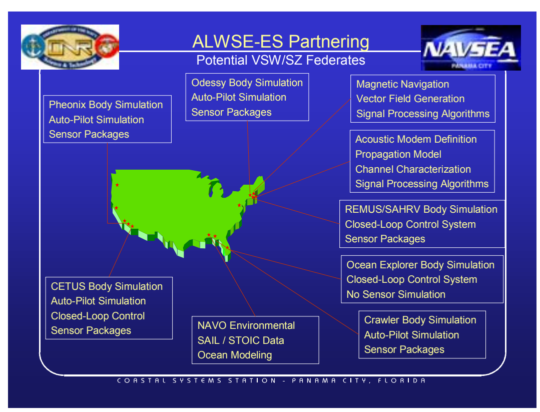

Figure 2
ALWSE-ES Partnering

In the littoral warfare area, there are a large number of models that either already exist or are being developed by a variety of organizations to describe the environment, the vehicles, the sensors, and the control systems.

Figure 2, ALWSE-ES Partnering, gives the reader a sense of the breadth of modeling efforts ongoing. The charter for ALWSE-ES is to bring these "off the shelf" physics models into one integrated simulation to characterize system performance. Models either exist or are under team development for all of the following:

- Vehicle motion: 3 degrees of freedom for bottom crawling (terrain effect) vehicles, and 6 degrees of freedom for the volume vehicles.
- Vehicle control: propulsion systems, control algorithms, and autopilots.
- Wave and current forces.
- Acoustic propagation models for the communications, navigation, and sonar sensors.
- Magnetic field generation.
- Sonar signal processing.
- Computer automated detection, classification and identification algorithms.

Simulation

Since no single group has all the pieces of the simulation puzzle, developing a simulation of the littoral systems and environment requires a teaming approach, with each team providing access to and support for its particular area of expertise. CSS is working to solve this problem by focusing on the joint development and integration of the required models, using existing DoD and Navy standards for interfacing and interoperability.

In efforts to better understand and characterize the physical world, subject matter experts (SMEs) may develop particular physics based models, in many cases without consideration for their incorporation into simulations or other types of tools. These models are tools that allow the SME to explore the trends of physical phenomenon. In some cases, SMEs don't need or want to know about the aspects of their model's use in a simulation. It is a daunting enough task to model the physics, and additional burdens of software interoperability should not draw them away from subject matter. To ease the burden of model integration and interoperability, the ALWSE-ES development team has adopted an Object Oriented Analysis and Design approach that allows the simulation to incorporate the SME's model.

Models are integrated within the simulation engine by representing them as objects, encapsulating their behavior and their characteristics within object classes. The simulation engine provides time management, control, and event processing functionality to exercise the models through time and space. This layer of abstraction in the simulation design will allow the characterization of many different classes of littoral systems while requiring minimal changes to the overall simulation design.

IMPLEMENTATION

Development Environment

The task facing the ALWSE-ES development team is not exclusively one of developing models, but rather putting them together into a simulation. The team decided that ALWSE-ES would be built for support of acquisition efforts not just in the near-term, but in the far-term as well, 10 to 20 years in the future. The focus would also be in the area of systems engineering and systems integration, providing a stable development environment for both. With this long-term vision in mind, it was decided first to invest resources in tackling the problem of building a development environment that could support the smooth integration of models. What should this development environment look like? The ALWSE-ES development team decided on a list of requirements that would maximize the level of code compartmentalization and reuse, as well as increase product stability and enhance manageable support. The requirements included:

- Incorporate Computer Aided Software Engineering (CASE) tools where possible to support our development from design to final code.
- Develop using Object Oriented Analysis and Design techniques to build a system that is modular and flexible.
- Support distribution over a network.
- Provide a mechanism for allowing developers to "hook" into external models that we would be integrating.
- Build an event-driven run-time capability that would operate both at real-time and faster than real-time.

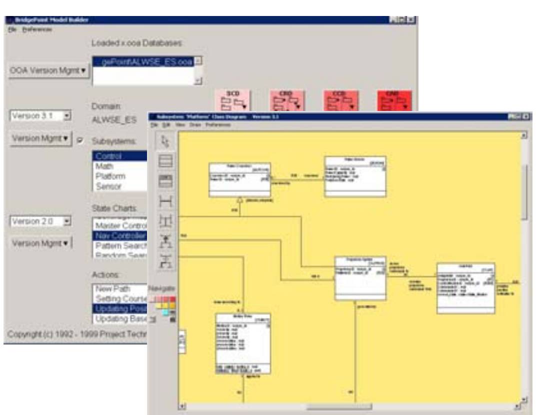

Figure 3
Bridgepoint Development Environment

After surveying the CASE tool industry, Project Technology's Bridgepoint was chosen to provide the core of the software development environment. Figure 3, Bridgepoint Development Environment, shows an example of the type of interface that the system modeler works with when designing ALWSE-ES. Bridgepoint offers a number of important features, but briefly, it allows a designer to specify his design through modeling tools and then compile the model directly into an executable program.

The ALWSE-ES development environment is quite different from the traditional paradigm of "requirements-design-code-build" in that all these activities are performed within the same environment within the context of the Object Oriented Design of the system. Figure 4, Schlaer/Mellor modeling, depicts the steps that the Schlaer/Mellor

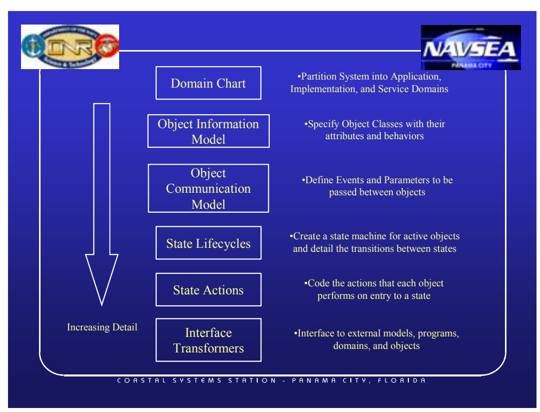

Figure 4
Schlaer/Mellor Modeling

methodology calls for during the development process. The designer uses a graphical user interface that implements the Schlaer/Mellor object oriented methodology, and he specifies the design of his software in increasing levels of detail within the Bridgepoint CASE tool. He partitions the system into separate domains organized by natural subject matter so that several teams can effectively work on the problem in parallel. He designs the structure of object classes using an Object Information Model. The Object Information Model describes the object classes, their attributes, and their relationships to other objects, as well as specifying interfaces to the external models. The communication between objects and the flow of control of the system is determined by events that are sent between objects. These events are described in an Object Communication Model. The behavior of each object class in the model is described using Object State Lifecycle diagrams, and each state is programmed using a State Action Language that the tool provides. In the state actions, the developer can put traditional programming constructs such as variables, control loops, if statements, external methods, and can generate events that are to be sent to other objects in the model. Finally, after doing all this modeling work, he invokes the model compiler, and the model compiler automatically generates source code, compiles it, and builds a run-time executable. This executable is the simulation engine, the core of ALWSE-ES that animates the models that are integrated.

Development Lifecycle

Figure 5, ALWSE-ES Development Cycle, depicts the development cycle adopted for implementing the engineering simulation. This development cycle centers on the primary activity of integrating and adapting "off-the-shelf" models. The beginning of the development cycle involves the identification of simulation requirements, describing the functionality, fidelity, resolution, and adaptability required from the models. The model survey activity identifies existing models or models that are under development that are candidates for incorporation within the simulation.

The developer's job is to tailor these existing models to fit within the ALWSE-ES environment, but first he must match the models against the requirements and adapt these models for integration. The models may exist in a number of forms, as stand-alone applications, as source code segments, and as algorithms that have been described but not coded. ALWSE-ES views these models as black boxes that are not to be changed, but only integrated within the ALWSE-ES environment. A suitable model for integration, therefore, will provide an interface that hides the details of the model implementation while leaving "hooks" for providing the information that is necessary to the model. During

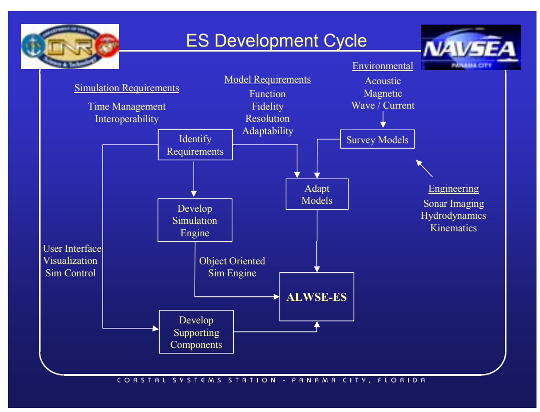

Figure 5
ALWSE-ES Development Cycle

the Adapt Models activity, the developer designs objects within the simulation engine that encapsulate model characteristics and interface to the models, and adapts the models to fit within the simulation environment. The simulation engine has requirements of its own such as time management and interoperability. Using the CASE tool, the developer implements engine components such as timers, events, and state machine lifecycles to animate the models. The simulation engine is the controlling backbone, or infrastructure of ALWSE-ES. Finally, the developer identifies user interface, visualization, and simulation control requirements that have to be supplied through supporting components such as the preprocessor and 3D visualization. The supporting components, the simulation engine, and the adapted models together form the architecture of ALWSE-ES.

Architecture

While the CASE tool implements the principle core of our system, the simulation engine, it is only one part of the architecture of our simulation. Figure 6, ALWSE-ES Architecture, provides a view of the complete ALWSE-ES architecture. Users provide

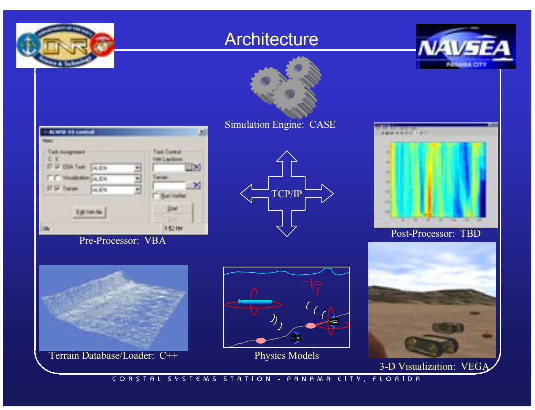

Figure 6
ALWSE-ES Architecture

inputs to the simulation, assign tasks over the network, and control the running of the simulation engine through the ALWSE-ES preprocessor program, built in visual basic. A terrain database using freeflight format files describes the bathymetry of the ocean floor. The physics models are provided by the model developers and can execute externally or in-line with the simulation engine. A 3-D visualization program allows an analyst to watch the progress of the simulation, while the data is captured and analyzed through the post-processor. Together, these components make up the ALWSE-ES simulation architecture, and they communicate through sockets using the TCP/IP protocol. One of the principle features of the architecture is that components can be distributed over the network, and in fact, the Bridgepoint CASE tool allows the developer to allocate the execution of the simulation engine component over computers on the network.

Model Integration Example

Figure 7, Model Integration Example, depicts an example of physics models integrated with the ALWSE-ES

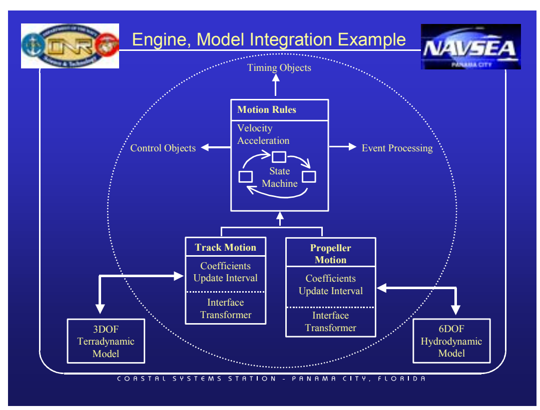

Figure 7
Model Integration Example

simulation engine. Items within the dotted circle are object classes within the simulation engine, while the items outside the circle represent the physics-based models provided by an SME. In this example, the track motion and propeller motion objects represent the motion models for the crawler and swimmer vehicles, respectively. These objects contain attributes that characterize the model, and specify the interface, referred to as an interface transformer, to the model. The software developer designs object classes to encapsulate the external model, and then "wires" the model to the simulation engine. The simulation engine provides the infrastructure in which the models will execute, and performs tasks such as object instantiation, deletion, event processing, simulation timing, and program control.

SUMMARY

What will ALWSE-ES be used for? The DoN Acquisition Reform Office has synthesized a common set of shared concepts from initiatives such as Simulation Based Design (SBD), Simulation Based Acquisition (SBA), System of Systems (SoS) development and testing, capability management, and integrated digital environments to derive policies, processes, standards, information sources, software tools, and cultural changes that will move Navy acquisitions away from the traditional "build-test-fix" paradigm. ALWSE-ES embraces these efforts and will perform an integral role in the acquisition of weapons systems for the littoral environment in years to come.

What kinds of problems can developers address using ALWSE-ES? ALWSE-ES allows developers to exercise prototypes and systems under development in a virtual littoral environment. With ALWSE-ES, they can answer questions about the performance of their system. Will sensors perform as expected, or will their performance degrade? Will signal-processing algorithms be able to sort through the clutter? Can vehicles successfully navigate and communicate in the environment? Will control systems fail during periods of navigation and communication outage? Can threats be identified and classified in murky surf waters? Which type of sensors will work best for automatic detection, classification, and identification? Have the right set of requirements been identified to achieve the mission?

In the future, ALWSE-ES will feature a hardware-in-the-loop testing capability. The virtual environment of ALWSE-ES will be augmented with integration to a live test range.

It is clear that the need for structured simulation based analysis exists. System and environmental complexities will not allow the effective and reliable development and assessment of systems and system-of-systems without a flexible and capable simulation environment. As technologies mature and systems acquisition efforts advance for use in the littoral region, ALWSE-ES will be available to provide the required advanced weapons systems development support.