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DESIGN AND CAPABILITIES OF AN ENHANCED NAVAL MINE WARFARE SIMULATION FRAMEWORK

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ABSTRACT

The Naval Surface Warfare Center, Panama City Division (NSWC PCD) designed and implemented a new tool, The Rapid Mine Simulation System Enterprise Architecture (RMSSEA), to support existing naval mine warfare simulations and to provide enhanced future mine warfare capabilities. RMSSEA supports existing physics-based models of Navy assets and threats in order to provide ship susceptibility and sweep effectiveness measures. The tool expands support for modeling of future systems, including maneuverable surface and underwater unmanned systems. Additionally, RMSSEA allows for simulations of distributed sensor and mobile warhead devices. The tool incorporates improved automation and visualization, which reduces simulation setup time and supports increased focus on results analysis.

1 INTRODUCTION

The Total Mine Simulation System (TMSS) is a simulation utilized by a number of countries to simulate one-on-one naval mine warfare scenarios. The US Navy uses TMSS for applications including operational sweep systems effectiveness, operational surface ship susceptibility, sweep system design tradeoff studies, ship (and submarine) silencing system tradeoff studies, and ship live fire with Follow-on Test and Evaluation (FOT&E). Though widely recognized as an important and powerful naval mine simulation tool, TMSS has displayed a number of shortcomings in recent years which hinder support for emerging and future modeling requirements. These shortcomings include lack of modern software development practices resulting in a system which is difficult to upgrade and maintain. This problem is partly due to the design limitation of one-on-one simulations with straight line target motion.

TMSS shortcomings led to the recognition of the need for a modernized simulation capability. A new simulation, the Rapid Mine Simulation System Enterprise Architecture (RMSSEA), designed and implemented by Naval Surface Warfare Center Panama City Division (NSWC PCD) will eventually replace the aging TMSS, providing increased capabilities, speed, ease of use and maintenance.

1.1 Purpose

This paper will provide a description of the newly developed simulation RMSSEA. At a high level, the simulation design and implementation will be discussed. Additionally, we will examine how RMSSEA overcomes the limitations of TMSS. Capabilities, such as simulation domain and entity types pertinent to naval mine warfare and analysis reporting, both initial and envisioned, will also be analyzed. Finally, a description of the simulation problem space will be described to illustrate the simulation system's usage.

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1.2 Scope

While this paper will provide a high level overview of RMSSEA design and usage, it is not intended to be highly detailed. RMSSEA is a large and complicated system which cannot be fully detailed in a single document. Detailed software design is beyond the scope of this document, as are any of the model details and equations upon which the simulation is based.

1.3 History

The Total Mine Simulation System (TMSS) has been in use by the US Navy since the 1980s. Originally developed as an in-house tool for the UK's Admiralty Research Establishment (ARE), TMSS has now been installed in weapons research establishments around the world. TMSS consists of a suite of simulation and assessment software providing a framework within which the interaction of signatures, sensors, and mine algorithms may be rigorously investigated and evaluated. Input may be in the form of real ship data or previously calculated coefficients for use by complementary environmental models with TMSS. Such models are capable of predicting a ship's influence at points other than the original recording position. Mines are defined within the system in terms of the characteristics of their sensors and the behavior of their algorithms. TMSS is designed so that users may design and implement their own sensor models and mine algorithms within the framework provided.

Simulation results used in a susceptibility analysis are organized and presented in several analytical outputs. Typical graphical data presentations are shown in Figure 1. Figure 1 shows the onset of look and actuation contour. The format shows the farthest distance abeam as a function of water depth from the watercraft that a mine will fire or satisfy the particular influence.

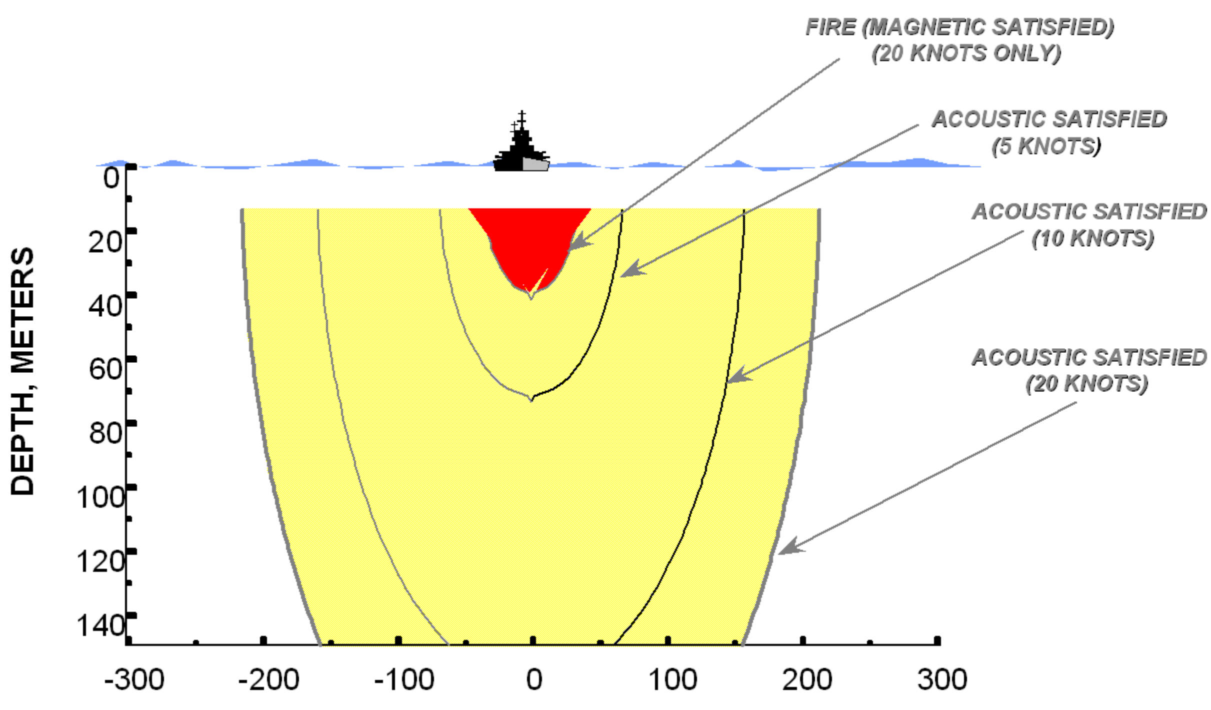

Figure 1: Onset of Look and Actuation Contour

Naval Surface Warfare Center Panama City Division (NSWC PCD), the world leader in Mine Warfare, Mine Systems & Countermeasures, has used TMSS in support of numerous studies as well as direct-fleet support since the late 1980s. All models currently used by NSWC PCD in the TMSS simulation environment have been entirely developed by NSWC PCD. The U.S. configuration of TMSS has supported, among many other traditional programs, several mine countermeasures (MCM) sweep system development programs as well as the DDG-51, DDG-1000, LPD-17, and other surface ship platform development programs.

2 DESIGN

2.1 Design Methodology

The current implementation of TMSS is written in standard FORTRAN and executes a variety of models written in a mix of the FORTRAN and C languages. What is lacking in the current implementation is many of the state of the art software development practices such as object oriented design and current-generation developmental tool sets that provide automated reporting and code generation. These limitations leave the TMSS code difficult to upgrade and maintain. To overcome the shortcomings, RMSSEA has been developed with object oriented design and analysis techniques from the beginning. It is being implemented under the Microsoft .Net framework, allowing for utilization of the integrated Microsoft tool sets. This also provides the flexibility of integrating legacy C and FORTRAN models into the simulation. A CASE tool is also utilized for code generation and documentation.

2.2 Distributed Execution

In designing the RMSSEA simulation architecture, the primary concerns included flexibility, speed, and ease of use. As part of the effort to facilitate these concerns, a distributed architecture of computers is utilized to process simulation scenarios in parallel. As seen in Figure 2, the simulation maintains a central database server for storage of all scenario initialization and data collection facilities. There is also a centralized distribution server which receives simulation requests from clients and distributes the tasking among a multitude of Execution Nodes.

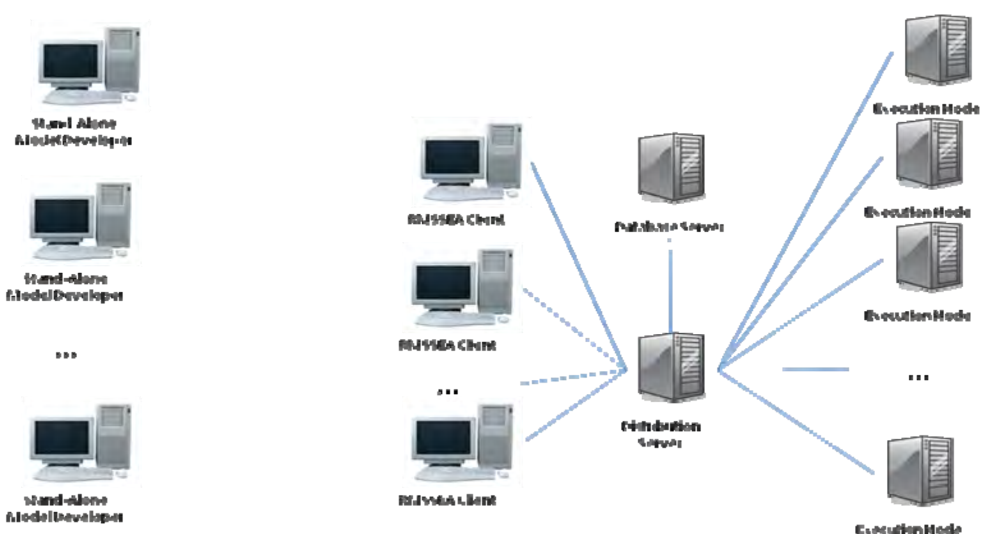

Figure 2: Distributed Architecture

Graphical user interfaces (GUIs) exist on clients for easily entering data into the simulation and preparing for execution. Each Execution Node is capable of executing a series of simulation scenarios, as tasked by the Distribution Server, and storing the results back to the centralized Database Server. It is notable from the figure that there also exist stand alone installations of RMSSEA, which will be used for testing and developmental purposes, but the vision is to have executing simulations being processed on the network.

All hardware systems within the simulation are standard PC architecture executing under various Windows based environments. The distributed environment is designed for flexibility and scalability with centralized data storage.

2.3 Model Integration

Though much of the simulation utilizes standard components such as GUIs and server components, a relatively unique method is employed to facilitate the flexibility of the system on the back end, in the Execution Node components. Here, rather than utilizing a standard fixed code segment for each model in the back end, the Execution Node itself provides only highly generic time keeping and communications facilities. The simulation models, such as acoustic propagation, ship signatures, motion, etc… are all maintained within the centralized database in binary format. When the Execution Node is tasked with a portion of a scenario to execute, it synchronizes the binary libraries from the centralized database server with local storage. It then utilizes the locally cached libraries to perform execution as required.

This unique approach provides nearly complete independence between model and simulation development. Aside from implementing a few simulation specific interfaces, each model needs to know relatively little about the simulation itself and how it executes. Each model uses a publish/subscribe mechanism where it independently publishes data which it is able to provide and similarly subscribes to data which it wishes to consume. Thus, models are generally free from knowledge of not only the simulation but other models as well. This places a burden on developers to carefully define and closely adhere to interfaces between models which define data communication, but then binds models to those interfaces, rather than to the models on the other side of the communications interface.

3 CAPABILITIES

The simulation environment is envisioned as a standard model of entities moving within and interacting through a defined environment. Entities and environments are composed of, and defined by, meta information and models attached to the entity or environment. Each entity can communicate internally between models for models it encapsulates, or externally to models in the environment or other entities, in either case using the publish/subscribe mechanism implemented by the system. Entities are commonly referenced as Assets for Blue Force and Weapons for Red Force, though there are few implementation details separating the two beyond this mental mapping.

Historically in TMSS, assets have been defined by a simplified constant-velocity straight-line motion model, a set of signatures and tightly associated propagation models that define the asset. Mines have been defined by a set of sensors that receive various influences and an algorithm or logic model that receives sensor outputs, compares threshold levels, implements timing requirements, and controls the actuation decision. The interaction space of the simulation is attached to both the asset motion model by way of starting positions – initial starting position and closest point of approach – as well as the simulation definition itself with the water depth and therefore depth of a moored or bottom influence mine. RMSSEA maintains this simplified approach for one-on-one simulations, while expanding support for more flexible definitions of the interaction space, including dynamic motion models - accelerating, turning, diving – and more support for mine types beyond the simple explode-in-place bottom influence mine.

3.1 Assets and Weapons

Assets in RMSSEA are associated with meta information describing the basic asset physical description, and models that describe relevant parts of the asset within the context of the simulation. An asset includes an internal publish/subscribe board where models within the asset may communicate without that information being visible to the wider simulation environment. An asset starting position is defined by the parameters of an initialization model appropriate to the asset type, including helicopters, normal Naval surface ships and submarines, unmanned surface and underwater vehicles, and towed MCM sweep gear with airborne, surface, or underwater tow platforms. Models attached to the entity define asset motion, signature noise into the environment, sensors appropriate to the simulation, control models if decision-making capabilities are required, and damage models to assess weapon effects. These models are illustrated with a notional communications flow in Figure 3.

Weapons in RMSSEA, like assets, are associated with meta information describing the basic physical description, and relevant models implementing aspects of the device significant to the simulation. A weapon includes an internal publish/subscribe board where models within the asset communicate. Historically in TMSS, weapon models included only sensors and logic. In RMSSEA, weapons include the full range of model functions, allowing, for example, motion models to be attached to moored mines for motion in the water column, or to mines with a mobile warhead allowing the system to model rising mines and encapsulated torpedo devices.

3.2 Environments

Environments describe the entire encounter space, implement communications between entities through the global publish/subscribe board, provide for propagation of noise from one entity to another, and provide appropriate background noise where applicable. All connections through and within the environment are implemented using the publish/subscribe method.

Normal simulation engagement execution implements an initialization step followed by an iterative nominally-circular data flow until the simulation engagement completes. In the initialization stage, all models register events they will publish, and then subscribe to events they consume. Working backwards from the weapon logic model, the weapon logic model will internally subscribe to the output of one or more associated sensor models. The sensor model will subscribe externally to the influence output of the environment at the location of the sensor. The environment will calculate the background noise for that influence at that location (assuming a background model provides this data) and the influence model will sum that background with the outputs of propagation models valid for that influence type. Each propagation model will subscribe to each asset's published compatible signature, and calculate the propagated signature result for the asset at its location relative to the weapon sensor at its location. If the weapon logic makes a firing decision, the detonation event will be published to the environment where nearby assets can be informed and apply that detonation event to their internal damage models. This cycle continues until some condition causes the simulation engagement to complete, and the simulation continues to the next defined engagement.

3.3 Analysis

All simulation results are stored within the system SQL database. This provides a single consistent interface to all simulation results, for all engagements simulated for a given simulation study. Data stored in the database can be accessed either for individual or statistical results, depending on the type of data recorded and the needs of the analyst. For individual results, the analyst may require a plot of the propagated signature seen by a mine sensor time-correlated with the sensor response and logic decisions of the mine. This could support better understanding of the firing chain of the weapon, and the precise signature characteristics that satisfied the weapon firing decision. For statistical results, the analyst may want an output similar to Figure 1. This can illustrate multiple effects depending on needs, including the effects of increasing speed on susceptibility, the safe operating depth of a platform in a given signature condition, and the difference in ranges of satisfied influences for multi-sensor weapons.

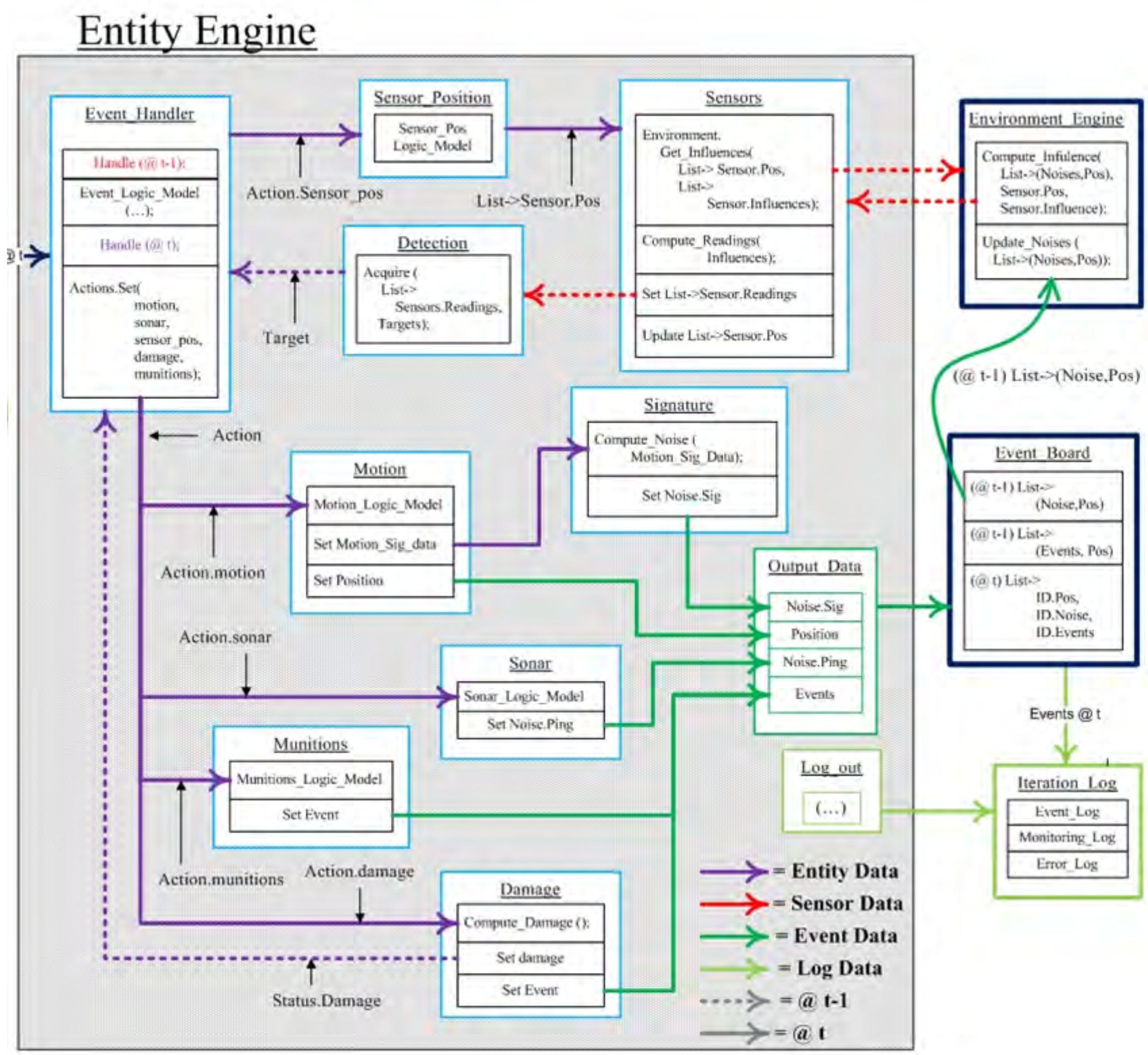

Figure 3: Entity Diagram

4 SYSTEM USE

RMSSEA defines a simulation as a hierarchical structure. A top-level RMSSEA simulation is a Study, which primarily exists as a container for Tasks. A Task in RMSSEA is a parameterized definition of the encounters of one or more assets with one or more weapons in a single environment. By supporting multiple independent values for parameters of models within a single task, a task can define one or more engagements of the asset(s) against the weapon(s) in the environment. Weapons, assets, and environments can be fully defined and stored in the RMSSEA database for usage in multiple studies, allowing quick definition of studies with standard configurations of assets or weapons.

4.1 Ship Susceptibility Studies

A common historical use of TMSS, and therefore an expected use of RMSSEA, is in the area of ship susceptibility. For this use, an asset is defined, possibly in multiple configurations, for the purpose of determining the total encounter space in which a threat weapon may be able to detect and come to a firing decision against that asset. Using the RMSSEA database of defined threats, an analyst must create only the defined asset under investigation. The RMSSEA study can use the database of pre-defined environments and weapons, ensuring that these are in standard and approved configurations. In this way, a study can be defined that completely simulates combinations of one-on-one engagements of a ship in multiple configurations versus multiple weapons with multiple settings, in a set of defined environments representing areas of interest. This study could be used for any of several uses briefly mentioned in the Introduction of this paper, including operational surface ship susceptibility and silencing system tradeoff studies.

4.2 Sweep Effectiveness Studies

Alternately, a study could be created which focuses more on the behavior of operational or developmental sweep systems. A simplified study of one-on-one simulations could be used to determine operational sweep effectiveness characteristics against specific threats, used as inputs in standard Navy planning tools. A more complex study could simulate a complete MCM operation, using a selection of Navy sweep assets in a defined minefield of threat weapons. Such a simulation could support analysis of alternatives to standard operational guidelines and development of experimental tactics.

5 CONCLUSION

Though TMSS has been utilized for many years to provide analysis support in the naval mine warfare community, a number of limitations and shortcomings have been seen over the years that the current implementation is not readily capable of overcoming. A redesign of the basic simulation framework is required to overcome these limitations and prepare for the future of simulation. That design and implementation is happening under RMSSEA. The RMSSEA design provides the full capabilities of TMSS but with far better usability and maintainability. RMSSEA will be more flexible and able to handle the simulation needs not only covered by the current TMSS implementation but well beyond. This paper has outlined the design of RMSSEA and how it will overcome many of TMSS's current limitations, as well as describe the capabilities and usage of RMSSEA.

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