# Distributed Simulation-Based Design of Collaborative AOSN Missions

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## LONG-TERM GOAL

A distributed, high resolution, robust and affordable concept for an Autonomous Oceanographic Sampling Network (AOSN) of undersea vehicles has been formulated to support vigorous hypothesis testing for resolving temporal and spatial gradients from distributed time series data over long periods of time. To support the development of an AOSN, the Ocean *SA*mpling *MO*bile *N*etwork (SAMON) System is being developed as a hierarchically distributed command and control concept for a multi-vehicle semiautonomous oceanographic and environmental data collection system. This effort involves the implementation of a simulation test bed facility for the analysis and design of AOSN systems in a virtual ocean environment. The goals include design of AOSN missions using distributed components from various research institutions and the development of a distributed library of vehicle behaviors. The scope of the simulation missions could include, oceanographic data gathering, mine counter measures and will be supported by a Geographical Integration System (GIS) and oceanographic prediction systems. Mission coordination and collaboration will be accomplished by drawing upon legacy software for internet-based distributed computing.

## OBJECTIVES

The objective of SAMON is to develop a web-based AOSN simulator to allow existing models of autonomous undersea vehicles (AUVs) at various research institutions to be integrated with programmable mission scripts, AUV behavior library and the command and control architecture developed in SAMON. This simulator software developed at the Applied Research Laboratory will integrate communications and environmental models, to provide an intelligent system for autonomous ocean sampling simulation.

The work formulates and implements a collaborative AOSN mission execution platform as a multi-vehicle self-organizing ocean sampling simulation test bed with the following features

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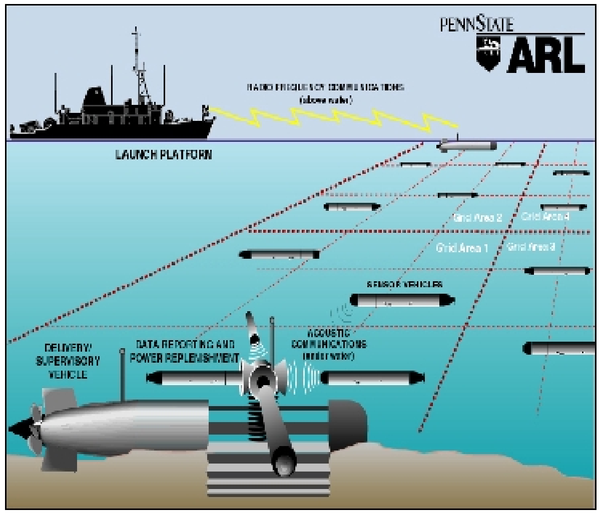



***1. Ocean SAMON hierarchy.***

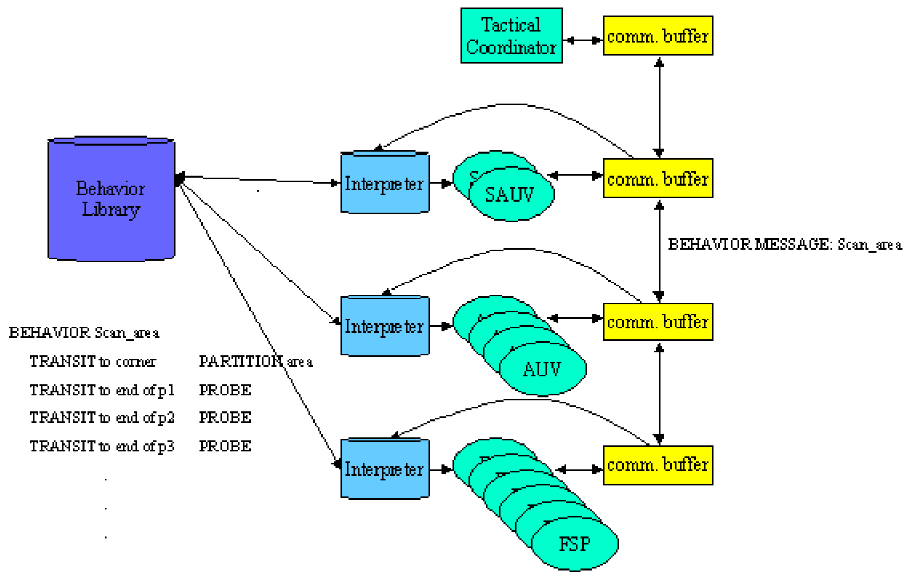
(1) a distributed hierarchical (Figure 1) control architecture which has the ability to develop mission scripts
(2) a resource bounded dynamic optimal execution of the developed mission scripts
(3) a library of AUV behaviors in databases that are accessible to vehicles at remote locations in various institutions
(4) a high resolution virtual ocean environment created from oceanographic data to test the robustness of the AOSN
(5) web based implementation and testing
(6) an oceanographic analysis system equipped with a display system and a GIS to process and integrate the collected AOSN data into existing data base and graphically display the results

A flexible architecture is being developed to integrate the above mentioned command and control concepts into the new simulation technologies. An instance of this architecture is being implemented at ARL. This architecture is suitable for use in real experiments and execution of actual missions using teams of AOSN vehicles. The purpose of this simulation is to (1) demonstrate the functioning of each entity in the AOSN, (2) demonstrate the robustness of the AOSN and its ability to reconfigure missions and (3) perform various experiments, e.g., data gathering, mine hunting, and reconnaissance.

**APPROACH**

SAMON is conceived as a hierarchy of four operational levels (see Figure 1): a Tactical Coordinator (TC) that sends commands to a collection of supervisory autonomous underwater vehicles (SAUVs), the second level, each of which in turn sends commands to a collection of autonomous underwater vehicles (AUVs) under its control, the third level. Each autonomous unit (SAUV or AUV) has responsibility to find and query fixed sensor packages (FSPs), the fourth level, that have been deployed in the area. These packages sample oceanographic data at their location at various depths. The SAUV and AUV units can also perform additional tasks, such as bottom mapping to gather high resolution bathymetric data, as they traverse their regions. A modification of the bottom mapping task can be used for search-based missions such as those that might be used in mine counter measures. The development of a general behavior message passing language (GBML) consisting of atomic actions common to all AUVs and a method for naturally composing these actions into more complex behaviors facilitates such mission modifications as well as creates a unified infrastructure for collaborative mission design involving heterogeneous components.

The GBML concept leads directly to the ability to generate and execute programmable mission scripts, which are high-level, behavior-based control strategies composed of complex behaviors performed either by an individual or by a group. These complex behaviors are further decomposed into atomic actions common to all AUVs. The atomic actions are interpreted by a wrapper (similar to how Java is interpreted by the Java Virtual Machine) so that the atomic actions will be hardware platform independent. This set of atomic actions, together with a set of composition rules for their combination into complex behaviors can then be used to develop a library of useful behaviors that can be readily accessed by individual AUVs, providing for distributed, dynamic execution of programmable mission scripts (see Figure 2).




***2. Distributed model of behavior based message passing.***

## WORK COMPLETED

- Implementated web-based SAMON server application
  - Developed Java GUI
  - Improved user interface including Ground Truth and Tactical Control displays
  - Introduced internet based communications using TCP/IP and Applink
- Integrated initial geographic information system capabilities
  - Integrated Arc/Info based capabilities
  - Created macro language and implemented GUI for Arc/Info
  - Developed ability to merge archived data with data collected during simulation producing higher information resolution
- Diversified experiment to include collection of high resolution bathymetry data
- Developed initial ocean environmental displays
  - Bathymetry
  - Temperature

  - Salinity
  - Pressure
- Incorporated data from Rutgers LEO15 experiment
- Developed initial interface with Harvard Oceanographic Prediction System (HOPS)

**RESULTS**

The Ocean SAMON controller implements a hierarchical control architecture. The development of a the testbed facility allows for virtual enactment of AOSN missions. Simulations performed with multiple simulations of vehicles successfully demonstrate the system's abilities for self-organization and adaptation to changing mission and environmental conditions.

To facilitate further modularization and distribution of the simulation, the SAMON project was migrated from a local application into a web-based environment. The Ground Truth GUI and Tactical Coordinator GUI were converted into JAVA, the GUI was reorganized using tab panels to improve controllability, new information visualization panels were added and old information panels were enhanced in the new GUI, which combined to provide a more suitable visual environment for the various stages of the simulation.

Oceanographic information was added to the newly implemented virtual environment panel. This virtual environment includes a bathymetric data display, vehicle information, and environment control. These panels provide additional means for observing the behavior of the simulation, showing the ocean data plotted with vehicles in their current positions as the simulation is updated every few seconds. In addition, we have begun implementing different types of data plots that may be displayed through the environment control sub-panel. This will enable the user to examine other oceanographic data such as temperature, pressure, and salinity.

In addition, communication between the GUI and the server was developed in TCP/IP with AppLink. This communication module enables the user commands to be sent to the vehicle controller and driver as well as the receiving of status information for the simulation from the server over the TCP/IP network.

The Environmental Assessment (EA) tool was developed to assemble data reported by the AOSN sensors into a coherent picture of the environment. The ArcInfo geographical information system (GIS), with its tools for archiving, interpolating, smoothing and displaying location-stamped information, provides the heart of the EA tool.

A simulation experiment was developed to demonstrate dynamic adaptation to the environment. The experiment utilized bathymetric data, and required high and low resolution bathymetry to be merged. The EA tool worked properly and the simulation experiment or demonstration was successful.

Finally, a more friendly user interface was added to the EA tool using the ArcInfo's Arc Macro Language ( the program's scripting language). This user interface allows the user to merge high and low resolution bathymetric data in real time.

## IMPACT/APPLICATION

The control architecture developed in this research provides a generic approach to modeling distributed autonomous systems. The controller software being developed can be downloaded into AOSN vehicles, providing an affordable approach to autonomous, distributed network operation and control. By augmenting the vehicles with an appropriate suite of sensors, this system can be extended to offer solutions to difficult problems such as mine hunting. The general behavior message passing language and software library of behaviors will provide a cohesive, platform independent method for communication between differing research institutions and their respective hardware implementations. The testbed facility can be utilized as a simulator for testing independently developed AOSN component simulations of AUVs of multiple organizations prior to joint in-water experiments. This establishes an AOSN mission execution infrastructure which, as shown in Figure 3, facilitates scaleable, collaborative mission simulations among researchers in the oceanography community.

## TRANSITIONS

It is expected that the Ocean SAMON controller software will become a key component of the AOSN and that the simulation testbed facility will provide an economical, integrated approach to virtual enactment of AOSN experiments prior to in-water testing. The distributed control architecture formulated in this research has potential use in a wide variety of autonomous control applications, i.e. mine hunting, autonomic and arsenal ship systems, space probes, flexible manufacturing systems, communications networks and transportation systems. In particular, we anticipate this technology being directly applicable to ongoing projects in the Very Shallow Water/Surf Zone (VSW/SZ) arena; we also anticipate further collaboration with the LEO15 experiments being performed at Rutgers University and with the Harvard Oceanographic Prediction System (HOPS).

## RELATED PROJECTS

The JFACC program supported by DARPA extends the research of this project to dynamic $C^2$ of air campaigns. Specifically, some of the key ideas in hierarchical command and control and in modular, distributed coordination of mission scripts for asynchronous parallel execution on multiple platforms are directly applicable to that project. In addition, we anticipate that the adaptation of GBML to accommodate aerial rather than underwater missions will be another natural extension of this research.

The ONR UCAV collaboration is another related program which is exploring distributed control of intelligent agents. The tradeoffs made in autonomy and intelligent control in the SAMON architecture are directly relevant to this program.

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