

OCEAN SAMPLING MOBILE NETWORK CONTROLLER

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LONG-TERM GOALS

A 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 [Curtin 93, Phoha 97a, Phoha 97b]. To support the development of an AOSN, the Ocean SAMpling MOBILE Network (SAMON) Controller (see Figure 1) 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 testbed facility for the analysis and design of AOSN systems in a realistic environment. The goals include simulation based design of AOSN missions using distributed components from various research institutions, the development of a distributed library of vehicle behaviors, and the creation of a common data model for those behaviors. Mission coordination and collaboration will be accomplished by drawing upon legacy software for internet-based distributed computing.

OBJECTIVES

The objectives of the proposed work are: (1) to implement a multi-vehicle self-organizing ocean sampling system simulator with a hierarchical autonomous control architecture, (2) to employ intelligent inferencing to circumvent limitations of sensor data, communications and equipment failures, and (3) to formulate and implement a collaborative AOSN mission execution infrastructure which incorporates a library of AUV behaviors in databases at various institutions and a modular controller architecture.

The AOSN simulator is being developed to allow existing models of autonomous undersea vehicles from other research institutions to be integrated with newly-developed technologies for command and

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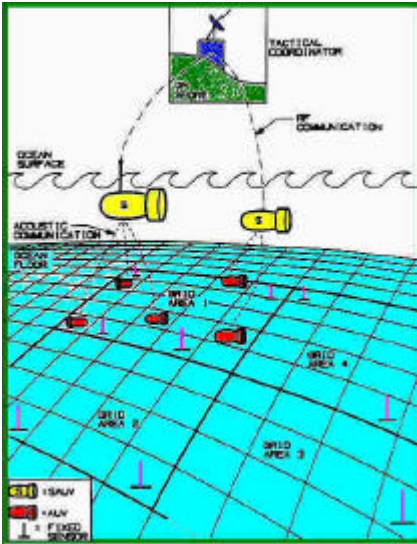


Figure 1. Ocean SAMON control hierarchy.

control (C^2) and intelligent controllers developed at the Applied Research Laboratory (ARL). Other software at the Information Systems Collaboratory at ARL, including communications and environmental models, will be integrated to provide an intelligent system for autonomous ocean sampling simulation.

A flexible controller architecture is being developed to integrate these new technologies. An instance of this architecture is being implemented as controller software suitable for use in the on-board processors of AOSN vehicles. Simulation software incorporating this controller is being developed for the purposes of (1) demonstrating the self-organizing/reconfiguring capabilities of the AOSN, (2) demonstrating the functioning of each autonomous component in the AOSN, (3) demonstrating the ability of the AOSN to adapt to dynamic environments and mission conditions, and (4) performing various hypothesis testing, e.g., performance measurements and architectural tradeoffs.

APPROACH

The Ocean SAMON Controller (see Figure 1) is conceived as a hierarchy of four operational levels: 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 autonomous units may also perform additional tasks, such as bottom mapping, as they traverse their regions.

The C^2 model which has been applied to formalize the AOSN mission control is based upon recent developments in systems theory [Phoha 92, Peluso 94, Peluso 96] which extend classical control theory concepts to characterize the time evolution of spatially distributed, interactive, discrete event driven autonomous systems. All nodes of the AOSN hierarchy represent individual autonomous vehicles, each of which has its own controller designed on a common architecture [Stover 96]. This controller, referred to as the SAMON Intelligent Controller (SIC) and shown in Figure 2, is modular,

configurable code which is replicated for each autonomous vehicle. The operational capabilities of an individual vehicle are determined by the set of behaviors incorporated into its controller. The command and control of the entire AOSN hierarchy is formalized as the Ocean SAMON Controller, and consists of the coordination and configuration (e.g. designation of a vehicle as an SAUV or AUV) of the individual SIC modules resident in each autonomous vehicle. This approach provides for (1) ease of development and maintenance, in that only one controller needs to be designed, and (2) network reconfiguration flexibility, in that vehicles can assume various roles as necessary. This framework facilitates the simulation-based design of collaborative AOSN missions utilizing distributed components prior to in-water testing.

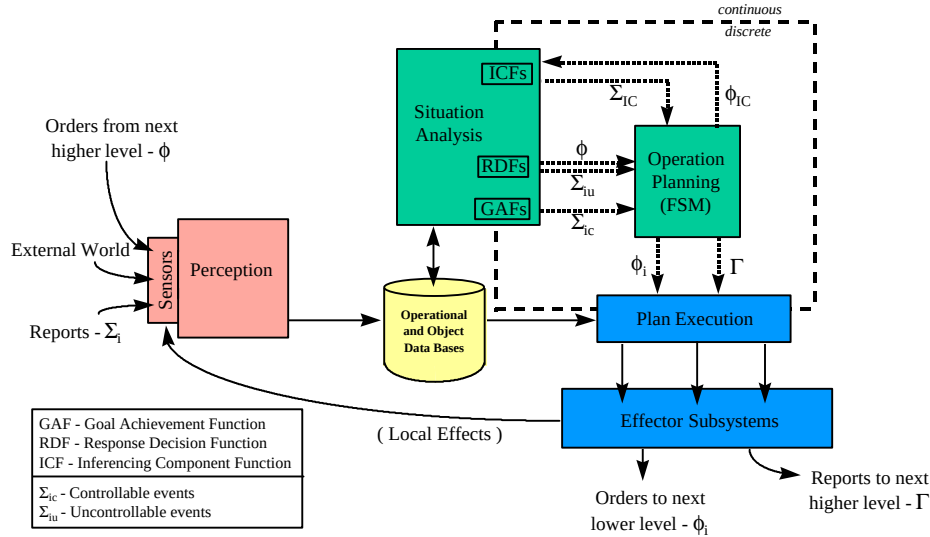


Figure 2. SAMON Intelligent Controller architecture [Phoha 97a, Phoha97b].

WORK COMPLETED

- System Architecture and Modeling
 - Completed information and event modeling for distributed, independent vehicle simulations
 - Modeled self-organization algorithms
 - Mathematical representation of automata model mapped to hierarchical controller design
- Controller and Simulator Development
 - Implementation of the hybrid hierarchical controller architecture for scaleable, nominal AOSN mission simulation
 - Integrated environmental models and sensor models into AOSN testbed facility
 - Designed AOSN topology configuration interface
 - Completed graphical user interfaces for ground truth comparison of mission parameters under limited observability conditions
- SAMON Intelligent Controller
 - Prototyped energy management behavior for SAUV/AUV refueling during simulated missions
 - Began development of a fuzzy-logic based Continuous Inference Network to implement energy management analysis and decision making
 - Extended SIC architecture to provide capability for virtual planning
- Test and Evaluation

- Implemented and debugged the SAMON Intelligent Controller for currently implemented AOSN mission simulations

RESULTS

The Ocean SAMON Controller implements the hybrid (continuous/discrete) hierarchical control architecture. The development of the testbed facility allows virtual enactment of the SAMON AOSN mission. Simulation experiments performed using multiple vehicles have successfully demonstrated the ability of this approach to provide a system that is capable of self-organization and able to dynamically adapt to changing mission and environmental conditions. This architecture has been shown to be conceptually rich enough to support the Ocean SAMON Controller mission. Data gathered during the simulated mission demonstrated the feasibility of the SAMON approach for adaptively following dynamic environmental conditions such as moving temperature fronts and highlighted observability issues.

IMPACT/APPLICATIONS

The network control architecture developed as part of this research provides a generic approach to modeling distributed autonomous systems. The controller software being developed in this effort 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 offers a new approach to difficult problems such as mine hunting. The testbed facility can be utilized as a simulator for testing independently developed AOSN components. This establishes an AOSN mission execution infrastructure which, as shown in Figure 3, facilitates scalable, collaborative mission simulations among researchers in the oceanography community.

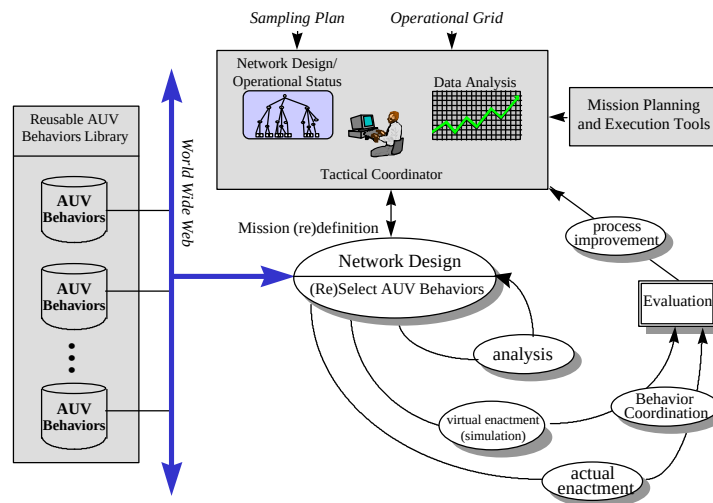


Figure 3. Virtual enactment of AOSN experiments over the internet.

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 testbed for virtual enactment of AOSN experiments prior to in-water testing. The distributed control architecture formulated in this effort has potential use in a wide variety of autonomous control applications, e.g.,

mine hunting, autonomic and arsenal ship systems, space probes, flexible manufacturing systems, communication networks, and transportation systems.

RELATED PROJECTS

As noted above, this effort leverages technologies supported by ONR under prime Navy SPAWAR (N00039-92-C-0100), U.S. Army CECOM (DAAH04-93-G-0290), and the Army Research Office. This effort also provides a fundamental foundation for collaborative efforts applying distributed, autonomous systems to ocean sampling including MIT's Odyssey class vehicle [Bellingham 94], Florida Atlantic University's Ocean Explorer [Smith 95], the solar powered vehicles of the Autonomous Undersea Systems Institute, and the ONR supported work of Turner et al. [Turner 96] on the organization and reorganization of AOSNs.

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