

Proposal Information

Sensors and Sensor Networks [NSF 03-512](#) Proposal Number

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Proposal Title

SENSORS: Ocean Observing System Instrument Network Infrastructure

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Summary – This proposal addresses the key technology issues of interfacing sensors with ocean observatories to a) decrease labor required for preparing, deploying and supporting instruments, b) ensure real-time and archived data is usable, c) make developing instruments for observatories easier, and d) provide pathways for the support of instruments not purpose-developed for observatories. If adopted by the community, this approach would allow interoperability of instruments between ocean observatories. The testing program proposed here, and the involvement of instrument manufacturers and observatory developers at other institutions, is structured to ensure that development of the instrument infrastructure is responsive to community needs and the results made widely available.

MBARI is applying distributed object, smart network, plug-and-work, and XML technologies to create a uniform software infrastructure to support the development, deployment, and operation of mooring based, deep ocean observing systems. Our goal is to simplify the problems of configuring, interfacing, and controlling instruments in networked observing systems with potentially intermittent and limited bandwidth, as well as simplifying access to, and management of, the data coming from such systems. We propose to adapt and prototype test the use of this infrastructure for MARS (Monterey Accelerated Research System), a cable based system being used to prototype a regional scale cable observing (RSCO) system.

Ocean observing systems have received increasing attention as a result of the growing recognition that ocean processes are still poorly understood, that oceans resources are not being adequately assessed and managed, and that ocean events such as the El Nino phenomena, can have a significant impact on public property, health and safety. Next generation cabled observatories will have bandwidths between 10s or even 100s of gigabits per second, and may support hundred or thousands of instruments. Thus reducing support requirements for instrumentation is essential for the economic viability of observatory facilities. The work proposed here would solve the key interfacing and data management problems by making the interface problem part of instrument development rather than an installation problem, and by handling commercial off the shelf instruments in a straight-forward easy manner.

There is now a pressing need to develop a uniform infrastructure to configure, interface, and control instruments as well as managing data from the instruments deployed in these systems. The specific challenge is to adapt and apply a variety of proven technologies developed for land based environments to the unique and demanding requirements of the ocean environment.

The specific problem addressed is how well does the infrastructure being developed for deep-ocean mooring based systems work for near shore, high-bandwidth, cable based systems.

Intellectual merit – This proposal addresses three main problems: 1) developing a standard instrument interface protocol and instrument adaptor (puck) that will simplify ease of configuration at sea, as well as automated device and service discovery in the system, 2) development of a standard methodology for describing instrument metadata, using XML technology, and a means for delivering sensor data, along with its metadata, to shore, and 3) a uniform application programming interface (API) using distributed object, client-server technology, that will simplify the task of controlling and accessing instruments by making the network layer transparent to the application developer. This will be a major step forward in bringing the benefits of current technology to ocean observing systems. We are making use of the tools, techniques, and products being developed by industry to address distributed computing networks of devices, and re-targeting them to the problems of a variety of ocean observatories.

Broader impacts - The products of this proposal will enable a lower cost of entry of a broad range of investigator's sensors in a variety of ocean observing systems and reliable collection of information (data and metadata) from sensors in those systems. These products will enable cost-effective collection of integrated, multidisciplinary data relevant to critical issues, such as ocean modeling and prediction, the climate system, the carbon cycle, natural hazards, littoral and deep water sensing, and biological processes in the ocean.

1. Introduction

This proposal addresses the key technology issues of interfacing sensors with ocean observatories to a) decrease labor required for preparing, deploying and supporting instruments, b) ensure real-time and archived data is usable, c) make developing instruments for observatories easier, and d) provide pathways for the support of instruments not purpose-developed for observatories. If adopted by the community, this approach would allow interoperability of instruments between ocean observatories. The testing program proposed here, and the involvement of instrument manufacturers and observatory developers at other institutions, is structured to ensure that development of the instrument infrastructure is responsive to community needs and the results made widely available.

The motivation can be understood from the following case history: each moorings supported by MBARI field 12 to 16 sensors and require over 100 days/year each for mooring integration and data support (the moorings are recovered and re-deployed once/year). Another important example is offered by the difficulty of integrating instruments onto ROVs, which are good analogs for seafloor observatories, since modern deep-ocean ROVs operate at the end of a fiber-optic tether. Next generation cabled observatories will have bandwidths between 10s or even 100s of gigabits per second, and may support hundred or thousands of instruments. Thus reducing support requirements for instrumentation is essential for the economic viability of observatory facilities. The work proposed here would solve the key interfacing and data management problems by making the interface problem part of instrument development rather than an installation problem.

There are recurring problems deploying scientific sensors and dealing with data from suites of sensors on ocean observatories, where sensors from many sources are deployed, diverse communications links are utilized, and where distributed, inter- and multi- disciplinary access may be required by users on shore. There is a specific problem in ensuring that the metadata required to properly interpret data from the observing system is created, maintained, and accessible along with the source of the data. It is critical that these problems be solved to enable continuous high-resolution measurements of oceanic processes and in support of distributed access and cooperation across multiple ocean observatories.

Our approach is based on two elements: 1) a hardware interface (“puck”) that contains persistent storage holding metadata about the instrument, along with a standard electrical interface, and 2) a software infrastructure and an application programming interface (API) that provides information about the system configuration, provides a means for controlling and accessing instruments and sensors and their, and provides methods for monitoring the status of systems elements.

An ocean observing system includes both commercial off the shelf instruments from many vendors as well as experimental research sensors deployed on variety of platforms, including moorings, autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), drifters, gliders, planes, satellites, and ships. These devices are networked with a variety of communication links, ranging from acoustic to wireless radio and satellite, to copper and optical fiber hard networks, resulting in a diversity of throughput, latency and reliability throughout the network. For deep ocean systems that are intended to serve a wide variety of scientific studies, network membership can be highly dynamic and unpredictable as links are connected and disconnected and devices are added to and removed from the observing system network. Each sensor has associated information about its history, calibrations and settings (“metadata”) necessary to interpret the data from the sensor. Keeping this association through the data acquisition, management and archival has been a chronic problem, even with conventional data acquisition.

MBARI is applying distributed object, smart network, plug-and-work, and XML technologies to create a uniform software infrastructure to support the development, deployment, and

operation of mooring based, deep ocean observing systems. Our goal is to simplify the problems of configuring, interfacing, and controlling instruments in networked observing systems with potentially intermittent and limited bandwidth, as well as simplifying access to, and management of, the data coming from such systems. We are already adapting technology for the MBARI Ocean Observing System (MOOS)¹ (Chaffey, Mellinger et al. 2001) to deal with the diversity of sensors, platforms and protocols through development of a standard hardware and software interface, and standard software infrastructure, that allows any sensor to be readily interfaced to, and integrated into, an ocean observatory (O'Reilly, Edgington et al. 2001). We are solving the diversity of communication links by adopting industry standard protocols where feasible and encapsulating non-standard protocols seamlessly. We address dynamic network membership and intermittence by utilizing smart network technology and plug-and-work² interfaces as well as our own technology and emerging industry standards in our standard software infrastructure. Our plug-and-work interface provides physical linkage of sensor as well as software to efficiently transport both the data and associated metadata throughout the observatory network to the data control, management and archiving systems. The infrastructure supports automated device and service discovery, as well as distributed access over a network to the instruments through distributed object client-server architecture.

As part of this proposal, we intend to implement a prototype of our standardized infrastructure for mooring based MOOS system for the NSF funded cable based MARS system planned for deployment in Monterey Bay in 2005. The MARS project is a field prototype for a larger Regional Cabled Seafloor Observatory. The product of this proposal is thus delivering a field proven sensor and instrument interface technology to the broader oceanographic community, through partnership, outreach and technology transfer. It will complement or facilitate other efforts to standardize common, web-based interfaces to distributed observing systems in support of cooperative science experiments involving multiple ocean observing systems. This product will be further demonstrated through participation in selected field programs, organization of workshops, and appropriate technology transfer partnerships.

1.1. Intellectual merit

The ocean science community has not had the benefits of remote, interactive, access to national level observing assets, that typically exist for the physics³, seismic⁴ and astronomical communities^{5, 6}. These communities have utilized and are continuing to utilize infrastructure advances in tera-scale computing, high performance storage, and networking, which are generally not available to the oceanographic community. As a result of a higher level of technology, they have also made strides towards using advanced technology for the remote command and control of instrumentation⁷.

This proposal aims to develop an *integrated systems approach* to the problems of configuring, interfacing, controlling, monitoring, and accessing instruments and sensors in a ocean observing system environment, as well as the problems of accessing and managing data and metadata from instruments in support of shore based data management and archival. This approach tackles observing systems in the worst case problem of deploying observing systems in the deep ocean. This problem is particularly challenging because of the constraints created

¹ http://www.mbari.org/rd/projects/current_projects.html#MOOS

² <http://www.upnp.org>, <http://sky.fit.qut.edu.au/~russells/itb564/notes/jini/jini.html>

³ <http://www.csm.ornl.gov/newVL.html>

⁴ <http://earthquake.usgs.gov/networks/global.html>

⁵ <http://www.us-vo.org/>

⁶ <http://nssdc.gsfc.nasa.gov/omniweb/ow.html>

⁷ <http://www.aquilent.com/scientific/nasa.shtml#irc>
<http://www.csm.ornl.gov/~geist/java/applets/uscope/>
<http://newt.phys.unsw.edu.au/~mcba/apt/guide.html>

by deployment in a deep ocean environment, by the potentially low power constraints of platforms, as well as the potentially intermittent, and low bandwidth nature of the communication links between platforms and instruments. It is challenging to design components to withstand the extreme pressure of the deep ocean that are robust enough to withstand long deployments with limited access for repair and maintenance, and can operate on limited power. The limited bandwidth may require smart local controllers that facilitate semi-autonomous event response that otherwise would be managed from shore. Another challenge is wide variety of oceanographic instrumentation, instrument interface protocols, as well as differing levels of complexity and maturity in devices and platforms, some of which are in differing stages of research and development.

This proposal addresses three main problems: 1) developing a standard instrument interface protocol and instrument adaptor (puck) that will simplify ease of configuration at sea, as well as automated device and service discovery in the system, 2) development of a standard methodology for describing instrument metadata, using XML technology, and a means for delivering sensor data, along with its metadata, to shore, and 3) a uniform application programming interface (API) using distributed object, client-server technology, that will simplify the task of controlling and accessing instruments by making the network layer transparent to the application developer. This will be a major step forward in bringing the benefits of current technology to ocean observing systems. We are making use of the tools, techniques and products being developed by industry to address distributed computing networks of devices, and re-targeting them to the problems of a variety of ocean observatories.

1.2. Broader impact

How well does the activity advance discovery and understanding while promoting teaching, training and learning? Much of the development described here will be carried out by students (MBARI interns) and a postdoctoral fellow.

Broad Dissemination to Enhance Scientific and Technological Understanding: 1) Results from this project will be published in prominent, peer-reviewed publications. 2) Software developed will be freely available on our web site under the open-source GNP public license. 3) We will conduct a workshop with members of the community on requirements for oceanographic observatory interfaces, present the results of our work at a public tutorial and at oceanographic technology conferences, and conduct a workshop to communicate our results and transfer the technology to the community.

Benefits to Society: The products of this proposal will enable a lower cost of entry of a broad range of investigator's sensors in a variety of ocean observing systems and reliable collection of information (data and metadata) from sensors in those systems. These products will enable cost-effective collection of integrated, multidisciplinary data relevant to critical issues, such as ocean modeling and prediction, the climate system, the carbon cycle, natural hazards, littoral and deep water sensing, and biological processes in the ocean.

2. Program description

2.1. Problem addressed

In current practice in oceanography the following tasks are tedious, labor intensive, error prone and complex: 1) configuring platforms to manage instruments, 2) interfacing an instrument onto a platform in an observing system, 3) configuring the system to communicate with this instrument, 4) accessing and acquiring data and metadata of instruments from shore, and 5) monitoring, operating, and maintaining platforms and instruments remotely. A lack of uniformity in the process and in interfaces to instruments further complicates the development of applications that use the instruments in a system, including applications that perform data management, data processing, visualization, and archival. As systems develop and grow, these problems will simply become worse.

MBARI has initiated a program of hardware and software infrastructure development to address these problems for mooring based system that may be deployed far from shore and in deep water. The basic requirements that are met by this observing system infrastructure are:

- System configuration

Determine what platforms and instruments are in the current system. Determine the basic characteristics of platforms and instruments. Determine the characteristics of the communication system including the bandwidth and latency of communication pathways. Provide notification if a communication link, platform or instrument is added to or removed from the system.

- Instrument Control.

Determine the power status of any platform or instrument in the system. Be able to turn power on or off where possible to any platform or instrument. (Note that some platforms may not support power control of individual devices). Where possible, be able to determine and alter the sampling rate of the instrument, determine and initiate a calibration, or initiate a sequence of events possible for the instrument.

- Data Acquisition.

Provide data and metadata on request or by establishing data and metadata streams from sensors or platforms in the system.

- System Monitoring, Diagnosis and Recovery

Provide system or status data and metadata for the communication system, sensors, and platforms in the system. Remotely install software upgrades and repairs. Provide system fault recovery mechanisms.

These requirements are to be met in a system constrained by: 1) The extreme environment of remote deep ocean deployment, 2) A wide diversity of sensors and 3) variable and intermittent communication links to shore and between sensor platforms. The infrastructure creates a uniform application interface for custom data processing of sensor data as well as a data management or archive system. It also provides a uniform instrument interface to the system infrastructure.

The **specific problem addressed** in this proposal is how well can the infrastructure being developed for deep ocean mooring based systems work for near shore, high-bandwidth, cable based systems.

2.2. Background

Since its inception in 1987 MBARI has been working with mooring based, long term observation systems to support biogeochemistry research in upper water column, including phytoplankton based ecology and El Nino phenomena. MBARI has traditionally focused its efforts on mooring based systems because of its focus on upper water column processes in the deep ocean (*Chavez et al*, 1997). Using ROVs, MBARI has been able to regularly visit deep ocean benthic sites over a wide area in support of benthic science and geology (*Barry et al*, 1996).

The trend on the U.S. East Coast has been toward cable based observatories near shore and in relatively shallow water on the continental shelf. For example, LEO-15⁸, offshore New Jersey, is a pioneering coastal observatory [*Grassle et al.*, 1998]. Established in 1992, the facility has now grown to incorporate dozens of instruments in water depths up to 40 meters. LEO-15 delivers data on water temperature, salinity, visibility, wave height, wave period,

⁸<http://marine.rutgers.edu/mrs/LEO/LEO15.html>

chlorophyll (phytoplankton) content, and current speeds and directions via fiber-optic cable from two offshore nodes.

The success of LEO-15 has prompted several other groups to install coastal cabled observatories for scientific study and monitoring [Glenn *et al.*, 2000]. Recently, the Katama observatory⁹ was established offshore Martha's Vineyard using LEO-15 technology. The observatory combines both oceanographic and atmospheric sensing. Oceanographic measurement programs include current and wave direction, sediment transport, and concentrations of carbon dioxide and other gases found in the ocean. The meteorological mast monitors gases in the air and weather data such as temperature, wind speed and pressure.

More recently a regional, plate scale cable-based ocean observatory has been proposed for the Juan De Fuca tectonic plate in the northeastern Pacific¹⁰. In 2002, NSF approved MARS (Monterey Accelerated Research System), a proposal to deploy a cable-based prototype near-shore observing system in Monterey Bay in 2005. Similarly the DEOS Working Group has recently released a report with a study of the need for a global network of mooring based observatory systems (DEOS Moored-Buoy Observatory Working Group. 2003).

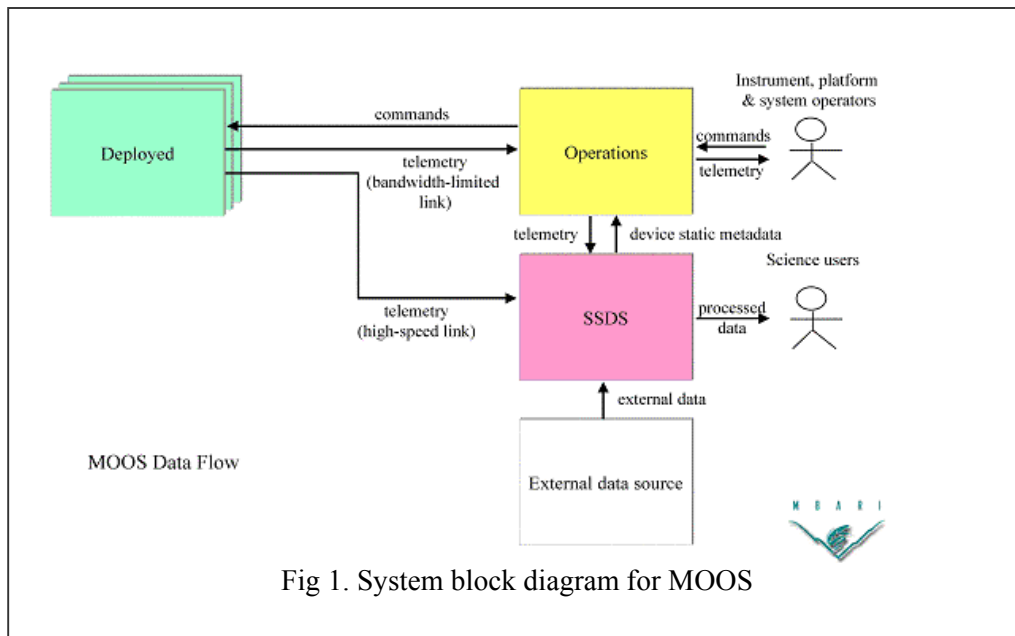


Fig 1. System block diagram for MOOS

In 1999, MBARI initiated a long-term strategic program to develop technology for state-of-the-art ocean observing systems to support future scientific research in Monterey Bay, as well as other sites of interest to scientists at MBARI and their colleagues at other institutions. There are many elements to this effort, a key one of which is a uniform infrastructure that provides the basic functionality required by users for configuring, accessing and controlling instruments used in an observatory deployment. The observing system project for Monterey is called the MBARI Ocean Observing System (MOOS)¹¹.

⁹ <http://www.whoi.edu/air-sea/observatory.htm>

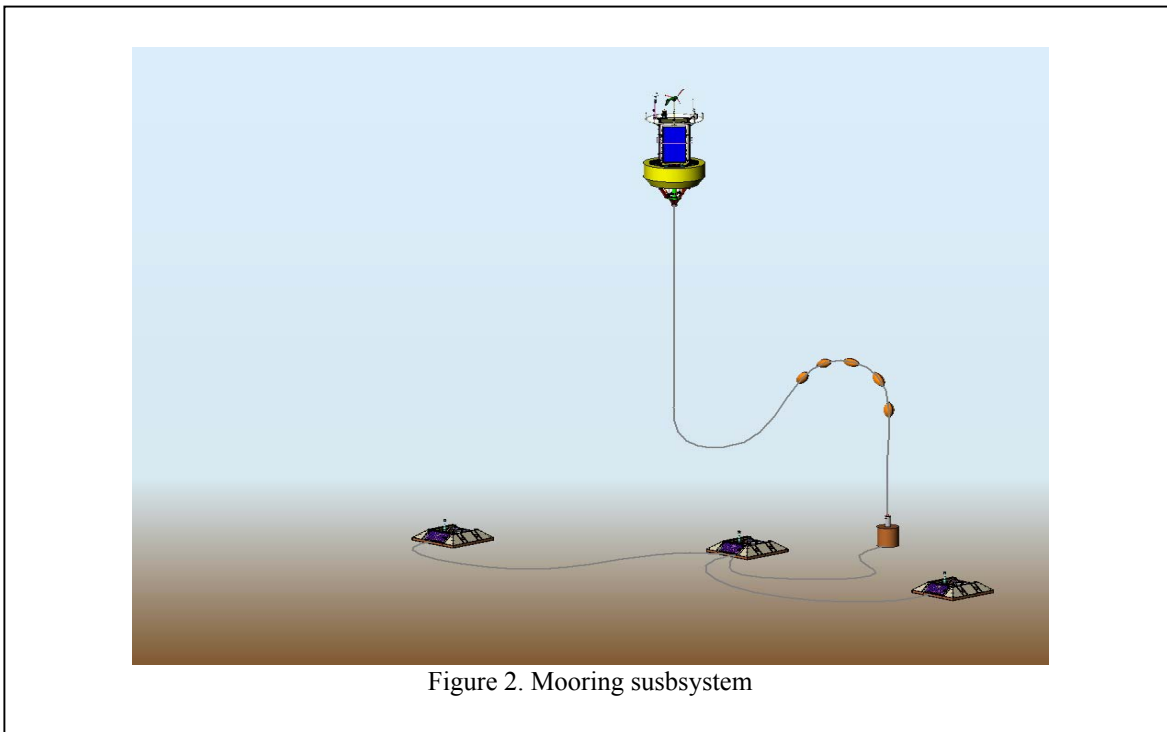
¹⁰ http://www.neptune.washington.edu/pub/whats_neptune/whats_neptune.html

¹¹ http://www.mbari.org/rd/projects/current_projects.html#MOOS

2.2.1. Overview of the MOOS System.

A system diagram for MOOS system is shown in Fig. 1. The system now under development will enable coordinated data acquisition from a diverse set of sensors, instruments and platforms. MOOS infrastructure software is already in the prototype stages of implementation at MBARI. The system requirements that are driving the design and implementation are the result of several years of analysis of the available technology and the proposed scientific uses of the system, as well as ongoing deployments of prototypes dedicated to specific science experiments¹¹.

A portable mooring system, shown in Fig. 2, with attached seafloor fiber optic network is the primary element of MOOS; this platform will host surface, mid-water, and benthic instruments, as well as a vertical profiler and docking station for autonomous underwater vehicles (AUVs). The mooring will be but one component of a much broader ocean observing network, which incorporates ships, ROVs, AUVs, drifters, and other instrument platforms. These platforms (some already existing, some yet to be developed) will enable data collection over a broad geographic area and throughout the oceanic water column, from the sea surface mixed layer and euphotic zone, through the midwater, to a deep ocean seafloor network of benthic stations.



The instruments themselves will range from current-off-the-shelf (COTS) instruments such as CTDs and fluorometers, to novel custom-made devices developed at MBARI and elsewhere. Instrument command interfaces are very diverse, as currently there are no widely accepted interface standards; thus the MOOS network software architecture must accommodate a wide variety of protocols.

2.2.2. The Deployed Subsystem

The deployed subsystem is the part of the system deployed at sea and can consist of moorings, ships, UUVs and a benthic network of substations connected to the surface by fiber

optic links through a riser to a mooring, and then by radio or satellite links, to shore. The subsystem nodes may also include a variety of UUVs in intermittent acoustic communication with local subsystem elements. UUVs may also 'dock' with subsystem elements and directly download data for transmission to shore through communication links. The deployed subsystem is also referred to as the 'wet side' of the system.

2.2.3. Shore Side Data Subsystem

A companion to the MOOS 'wet side' is a shore side data system (SSDS); also referred to as the 'dry side'. The SSDS is to be the repository for all the scientific data collected, and to provide users with access to this data. A primary requirement is to insure that all the metadata required for properly describing and interpreting the data from the system instruments is collected, catalogued, and accessible along with the data. In the context of a highly flexible and reconfigurable observing system such as MOOS, this problem is particularly challenging. The SSDS also provides a capability for accessing data sources external to the MOOS system.

2.2.4. Operational Subsystem

An important aspect of the MOOS system is the operational need to monitor, control, diagnose and recover from system failures in 'real time'. This places further demands on the MOOS architecture. The architecture must be capable of capturing the current status of system elements (sensors, instruments, platforms and communication links), as well as controlling and modifying them. An audit trail or 'history' of the system state is also required to support diagnostics and recovery and to fully identify the system state as an aspect of data interpretation. Additional system metadata must be accessible to support the operational subsystem.

2.3. Approach

In this section we give an overview of the existing approach to meet the requirements for the infrastructure used in the MOOS program followed by a proposed approach that can be used to adapt and test this system for use with the MARS cable based system.

2.3.1. Approach for the existing MOOS effort

The problems to be addressed require two kinds of interfaces. The first is a software infrastructure and an application programming interface (API), to the system infrastructure that 1) provides information about the system configuration including its platforms, instruments, sensors, the communication links, and services provided by its elements, 2) provides a means for controlling and accessing instruments and sensors and their services, as well as obtaining data and metadata from system sensors, and 3) provides methods for monitoring the status of systems elements, diagnosing system failures, as well as remotely initiating recovery, and installing repairs and upgrades. The second interface is the hardware/software interface between the system infrastructure and devices that may be added to or removed from the system.

The approach is to develop standardized interfaces of each type using industry proven technologies throughout. The standard application software interface has been designed using a distributed object, client-server software base. In the object approach, written in an object oriented language such as JAVA, each object in the system is represented by a class object with methods that can be used to communicate with the object. There are classes of devices, and subclasses, including platforms, instruments, and sensors. In the distributed object approach these objects are made available over the network through proxy objects which can be invoked locally(*O'Reilly et al* 2001). In the smart network plug-and-work environment, services appear and disappear as device objects come and go. Applications can be notified when services, or server objects appear. Applications invoke these services as clients over the network through a proxy object. There is no need for the application to know anything about the underlying network, and the application is presented with what appears to be an object

environment that reflects the actual set of platforms, instrument, and sensor that make up the system.

In the “traditional” method of installing a sensor, a technician must typically physically install the device, obtain and install device server and driver software, calibration, metadata and configuration files onto the host, and finally modify a host configuration file (specify sensor’s serial port address, name of server/driver to execute, etc.). These steps require a person with specialized knowledge, and can be time-consuming, tedious, and hence error-prone.

The MOOS standard instrument interface is based on the concept of a hardware adapter, or ‘puck’, that uses a standard serial protocol, and intermediate puck based functions that identify the device to the system, along with any associated metadata, upload the metadata and a driver, and thus establish on the system a server object that is then used to control and access data from the instrument (Fig. 3). This approach thus implements automated device and service discovery.

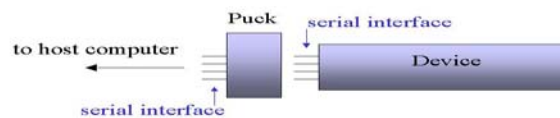


Fig. 3 Puck Instrument Adapter

In the plug-and-work model used for MOOS, anyone simply plugs the device into an arbitrary serial port on the host; the host and device then *automatically* cooperate to install the necessary software, metadata, and configuration information, and the device server/driver software begins running on the host.

In order for this to work, the host must be able to retrieve information from the device at the time of device plug-in. Thus persistent storage is required on the device, as well as a standard protocol for retrieval of the device information through its serial interface.

Most sensors available today do not provide persistent storage of arbitrary information, let alone a standard for retrieval of that information. That is why a device puck is required. The puck persistently stores information about the device, is physically closely coupled to that device, and always travels with that device. The puck has two serial interfaces; one interface to the host, and the other RS232/422 interface to the sensor itself. In addition to persistent storage, the puck also contains a microprocessor, which controls reading and writing to the persistent storage. In *puck command mode*, the host can either read or write the puck’s persistent storage. In *puck pass-through* mode, the puck simply passes host commands or sensor data through.

A significant element of the MOOS approach is an integrated approach to the metadata problem by using XML technology¹². Instruments to be deployed in the system are required to be ‘qualified’ prior to being deployed. The qualification steps include the configuration of a ‘puck’

¹²<http://www.w3.org/XML/>

interface that enables the instrument to upload its device driver to its host node in the system. But another part of qualification is to require the instrument user to fill out a metadata form that captures not only all the scientific metadata required by the user but also system data required by the infrastructure as well as the shore side data management system. In particular each device is assigned a unique puck identifier, which serves as a key to all the information about that device. The metadata form is a user-friendly application built using GUI technology from a metadata W3C XML schema designed for each class of devices that must be qualified (*Davis et al.* 2002). Although the user of the form only supplies informational data, the metadata form user application actually generates a syntactically correct XML document, conforming to its schema, that is then stored in persistent storage on the instrument's puck. This metadata in XML syntax is uploaded to the instrument's host node when the device is plugged into the system at sea and is therefore available as soon as data from the instrument is available. A last step in qualification is that all the functions of the instrument-puck are fully tested in the lab in a simulation environment to ensure that the device driver, service discovery, instrument control, and data and metadata access are working properly, prior to deployment. This approach further guarantees that the metadata required by the data management system or users on shore is available. This also further facilitates the development of applications that require standardized metadata to automate the processing and display of data from the system. MBARI is currently participating, as an ex-officio member, in an international effort, the Marine XML Project¹³, to standardize the use of XML for marine information.

2.3.2. Analysis and Comparison of Requirements.

The basic approach to adapting the MOOS infrastructure to MARS is to analyze the requirements of the MARS cable based system and compare it with the requirements and design features of the existing MOOS system. We will then determine if there are any capabilities required by the MARS system not provided by the MOOS system. Since the constraints on the MOOS infrastructure are in general greater than the MARS system we believe it is unlikely that the MOOS infrastructure will fail to meet the requirements of MARS. All of the requirements presently identified for MOOS are, not surprisingly, identified as well for MARS. The main differences are that some of the technologies presently utilized for MOOS, namely distributed object, plug-and-work, automated device and service discovery and use of XML for metadata have not been specifically identified for use in MARS, even though these technologies are being used to address requirements in MOOS that exist, in principle, for MARS.

2.3.3. Adaptation of MOOS Technology to MARS.

The MOOS infrastructure was developed with an assumption that communication links to shore would have limited bandwidth, and that nodes in the deployed system would likely have limited power. These constraints lead to the viewpoint that host nodes in the deployed system need to have forward processing power to support automated event detection or to process or compress data to be sent to shore. In a cable-based system these constraints are relaxed, and it can be assumed that essentially all event detection and data processing could take place on shore. A goal of this proposal is to explore whether or not the MOOS architecture need be altered in the face of these reduced constraints. This will be the purpose of prototype tests on the adaptation of MOOS technology to MARS.

A specific adaptation is to modify the Puck interfaces to present either an Ethernet port or a standard serial port to the instrument (depending upon its requirements), and present to MARS all the software and physical layer hardware necessary to connect to and communicate with MARS. We will address the needs of the spectrum of users, including technically sophisticated users developing new instruments that take full use of the observatory resources and provide

¹³ <http://www.marinexml.net/>

novel capabilities, as well as scientists using standard oceanographic instrumentation in traditional or novel ways.

2.3.4. Workshops on Infrastructure Technology

Part of the approach to the analysis and adaptation issues discussed above are to hold a series of workshops with MARS participants to identify and compare the requirements for the two systems. We also plan to discuss in general the issue of a uniform infrastructure approach to ocean observing systems. This includes the issue of a uniform approach to metadata requirements at the instrument interface level.

3. Proposed work

The proposed work implements the approach outlined in the above sections.

3.1. Analysis and comparison of requirements for mooring-based deep ocean and near shore cable-based ocean observing systems

Review the existing development program for both MOOS and MARS including requirement analysis, conceptual design, implementation plans and coordination with science experiments. We will hold a workshop to carry out this review and make recommendations for a uniform infrastructure approach, based on the MOOS technology, for both deep ocean mooring based systems and near-shore cable-based systems. We will publish the results of the workshop on the web and in hard copy. We will establish community access to our results via a moderated user group on the web.

3.2. Develop and implement plan to adapt and test prototype of MOOS technology on MARS

The purpose of this step is to develop a plan to implement the recommendations of the workshop regarding a uniform approach to both types of observing systems and to prototype test this infrastructure for MARS. The assumption is that most of the existing architecture for MOOS is readily adaptable to a cable-based observatory. For example the instrument puck technology should readily adapt to use on a cable-based observatory. The distributed object, client-server, and automated device and service discovery paradigms are all useful for MARS. Moreover, the mooring sub-system of MOOS includes a high bandwidth, local area network of benthic nodes connected to each other and a riser to the surface-mooring platform, so the MOOS system, at a local level, has cable-based elements. However, it is not clear that host nodes need be on remote platforms at sea for a near shore cable-based system. This issue will be carefully explored in the prototype tests.

3.3. Follow on workshop and dissemination of results

The third element of the proposed work is to hold an observing system infrastructure workshop to articulate and communicate to the community the lessons learned from the prototype test of the MOOS infrastructure in use on the MARS cabled system. This work will be carried out through a workshop report and published articles. In particular we plan to disseminate to the community through these workshops what is learned about the feasibility of a uniform infrastructure for future ocean observing systems.

4. Milestones and deliverables

First year - Plan and organize a workshop with MARS partners to identify, analyze and compare requirements for the MOOS and MARS systems, and develop the general requirements and objectives for a prototype test of the MOOS technology on the MARS cable-based hardware infrastructure. The analyses will take into account the type of science experiments that will be served by the MARS system. The specific deliverable will be a workshop report describing the issues, results and recommendations of the workshop.

Second year

It is expected that the hardware to be deployed for MARS will be available for on-shore testing during this year. The proposed work will be to develop and implement a prototype test of the MOOS technology using the actual MARS hardware. This test will implement the same

basic functionality that has already been prototyped at MBARI for this technology. It includes implementation of the distributed object, smart network technology and application programming interface on a host node connected to the hardware communication links. It also includes instrument and sensor configuration tests for a suite of typical instruments required for an actual deployment, including the development of drivers, and device metadata, as well as plug and work tests for automated device and service discovery. It includes a test of the instrument puck concept for the same system. Finally a series of tests will be performed with smart host nodes at the deep ocean end as well as host nodes only on the shore end. The deliverables are the prototype infrastructure software adapted to MARS, as well as the results of the tests, which will be presented at the third year workshop and presented as a tutorial session at an appropriate national oceanographic technology conference, such as MTS/IEEE Oceans Conference.

Third year

A follow-on workshop will be organized and held to report the results of the prototype tests on the use of MOOS technology for MARS, a discussion of lessons learned, as well as a general follow-on discussion of the feasibility of a uniform software infrastructure for ocean observing systems. The plan will be to invite participants from the broader community involved in the development of observing systems. The purpose of this workshop will be to foster a better understanding of the problems, the applicable technology, and what is known, with the goal of defining a more coherent direction for efforts in this area. The primary deliverable will be a workshop report describing the proceedings of the workshop as well as recommendations on how to proceed in further efforts.

5. Integration of Research and Education

MBARI runs an active summer internship program¹⁴ open to teachers and students (undergraduate and graduate level). The interns spend an intense 10 weeks working the PI's labs, with one day per week spent on participating in oceanographic cruises, field trips to oceanographic research facilities, and other activities amplifying the intern's exposure to oceanographic technology and science. Edgington has sponsored about two interns each summer in his group, mentored by engineers on a variety of technology projects. We expect that the opportunity to work on developing and testing standard interfaces for ocean observatories will provide interesting research projects to interns. Interns publish¹⁵ and present their work at an MBARI symposium at the end of the summer; their work often results in presentations and publication at national conferences in which they participate.

6. Integrating Diversity into NSF Programs, Projects, and Activities

MBARI integrates teaching and research via the summer internship program. Each intern is selected following a rigorous application procedure, merit review, and a telephone interview process. They are from around the world and represent a variety of different backgrounds, experience, and education. They all share a common desire to learn more about the marine environment and to work with the scientists and engineers at MBARI. The primary purpose of the intern's project is for the specific educational benefit of the intern and to make a contribution to the general good of the oceanographic community.

6.1. Outreach

The Monterey Bay Aquarium showcases the oceanographic research and technology development of MBARI through live lectures, delivered multiple times each day, attended by many of the 1.8 million annual visitors to the Aquarium. The lectures feature "Live-Link"¹⁶ display of data transmitted by microwave in real-time from MBARI research ships, supplemented by prerecorded data from earlier cruises and experiments. We will explore ways for the public to

¹⁴ <http://www.mbari.org/education/internship/genintern.html>

¹⁵ <http://www.mbari.org/education/internship/internpapers.htm>

¹⁶ <http://www.mbari.org/itd/retrospective/link.html>

learn of our research and see demonstrations of live, interesting data collected by the observatory by developing material that can be integrated by Aquarium staff into the *Live from Monterey Canyon* presentations.

7. Management plan

7.1. Meetings:

7.1.1 Workshops. We propose two workshops to be hosted at MBARI: one in year 1, and the second in year 3, each hosting 30 participants from the community. The first workshop brings together MARS participants and the community to identify the key requirements for interfacing instruments to deep water cabled observatories, and to compare the requirements to those developed for MBARI's MOOS observatory. The second workshop presents to the community the lessons learned from the lab and field tests of the project work, and offers a forum for other investigators to present their work and opinions in the area of instrument interface to observatories. The objective of the second workshop is to present the feasibility of standard infrastructure for future ocean observing systems. In each case the workshop proceedings will be published and made available on the project external website.

We propose in year 2 for the postdoctoral fellow and MBARI engineer to travel to an appropriate oceanographic technology conference (such as MTS/IEEE Oceans Conference¹⁷) and present the project product as a tutorial on how to integrate to the MARS observatory.

7.1.2 Specification of the engineering design is the responsibility of the PI and MBARI engineer on the project. Design reviews will be held to review requirements, and to review the design tradeoffs and decisions at concept design, preliminary design, and critical design points, according to standard engineering practices at MBARI. These reviews will be used to document design decisions and to get input on the design from the engineering staff at MBARI (28 engineers), and community members identified through the workshop process.

7.2 Project products:

Software development products will be hosted on a central CVS repository¹⁸, and problems and status tracked on a central moderated internet forum using YaBB¹⁹.

Project overview, documents and publications will be hosted on a project web site, on the MBARI external Internet computer server system.

Project participants and community members will be registered on a project Lyris²⁰ email listserver, hosted at MBARI, to facilitate communication amongst the community, and to archive email discussions for later reference.

Part of the budget for MBARI is for a part-time administrator and software technician, staffed at MBARI, to collect development products and to maintain CVS server, Forum system, project web site and listserver, documentation and other project products.

7.3 Fielded exercises:

Fielded exercises conducted during the summers will provide opportunities for community members and summer interns to test the prototype interface. The two planned exercises are:

- 1) Integration and test of instrument interface on the MARS shore-side test system.
- 2) Integration and test of instrument interface on the MARS deployed system.

¹⁷ <http://www.oceans2003.com/>

¹⁸ <http://www.cvshome.org/>

¹⁹ <http://www.yabbforum.com/>

²⁰ <http://www.lyris.com/>

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