

Workshop Proceedings



ENABLING SENSOR* INTEROPERABILITY

*Portland, Maine
October 16-18, 2006*

*Funded by NOAA's Coastal Services Center through
the Alliance for Coastal Technologies (ACT)*

* For the purpose of the workshop, participants spoke in terms of "instruments" rather than "sensors," defining an instrument as a device that contains one or more sensors or actuators and can convert signals from analog to digital.

An ACT Workshop Report

Enabling Sensor Interoperability

Portland, Maine
October 16-18, 2006



Sponsored by the Alliance for Coastal Technologies (ACT) and NOAA's Center for Coastal Ocean Research in the National Ocean Service.

Hosted by ACT Partner, Gulf of Maine Ocean Observing System.

ACT is committed to develop an active partnership of technology developers, deliverers, and users within regional, state, and federal environmental management communities to establish a testbed for demonstrating, evaluating, and verifying innovative technologies in monitoring sensors, platforms, and software for use in coastal habitats.

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EXECUTIVE SUMMARY

The ACT workshop “Enabling Sensor Interoperability” addressed the need for protocols at the hardware, firmware, and higher levels in order to attain instrument interoperability within and between ocean observing systems. For the purpose of the workshop, participants spoke in terms of “instruments” rather than “sensors,” defining an instrument as a device that contains one or more sensors or actuators and can convert signals from analog to digital.

An increase in the abundance, variety, and complexity of instruments and observing systems suggests that effective standards would greatly improve “plug-and-work” capabilities. However, there are few standards or standards bodies that currently address instrument interoperability and configuration.

Instrument interoperability issues span the length and breadth of these systems, from the measurement to the end user, including middleware services. There are three major components of instrument interoperability including physical, communication, and application/control layers. Participants identified the essential issues, current obstacles, and enabling technologies and standards, then came up with a series of short and long term solutions.

The top three recommended actions, deemed *achievable within 6 months* of the release of this report are:

- A list of recommendations for enabling instrument interoperability should be put together and distributed to instrument developers.
- A recommendation for funding sources to achieve instrument interoperability should be drafted. Funding should be provided (for example through NOPP or an IOOS request for proposals) to develop and demonstrate instrument interoperability technologies involving instrument manufacturers, observing system operators, and cyberinfrastructure groups.
- Program managers should be identified and made to understand that milestones for achieving instrument interoperability include a) selection of a methodology for uniquely identifying an instrument, b) development of a common protocol for automatic instrument discovery, c) agreement on uniform methods for measurements, d) enablement of end user controlled power cycling, and e) implementation of a registry component for IDs and attributes.

The top three recommended actions, deemed *achievable within 5 years* of the release of this report are:

- An ocean observing interoperability standards body should be established that addresses standards for a) metadata, b) commands, c) protocols, d) processes, e) exclusivity, and f) naming authorities.
- An annual symposium on ocean observing system engineering and operations and cyber infrastructure should be established. Characteristics of this symposium could include the presence of computer science graduate student proposals, peer-to-peer networks for fleets

of autonomous underwater vehicles, a collection of documents and functional artifacts, and should follow the Apache model.

- A research program responsible for the development and maintenance of an online “virtual” ocean observing system for computer science research should be established. A set of both operating and virtual ocean observing system samples would be provided for testing algorithms, use case scenarios, etc.

ALLIANCE FOR COASTAL TECHNOLOGIES

The Alliance for Coastal Technologies is a NOAA-funded partnership of research institutions, resource managers, and private sector companies dedicated to fostering the development and adoption of effective and reliable sensors and platforms. ACT is committed to providing the information required to select the most appropriate tools for studying and monitoring coastal environments. Program priorities include transitioning emerging technologies to operational use rapidly and effectively; maintaining a dialogue among technology users, developers, and providers; identifying technology needs and novel technologies; documenting technology performance and potential; and providing the Integrated Ocean Observing System (IOOS) with information required for the deployment of reliable and cost-effective networks.

To accomplish these goals, ACT provides these services to the community:

- Third-party testbed for quantitatively evaluating the performance of new and existing coastal technologies in the laboratory and under diverse environmental conditions.
- Capacity building through technology-specific workshops that review the current state of instrumentation, build consensus on future directions, and enhance communications between users and developers.
- Information clearinghouse through a searchable online database of environmental technologies and community discussion boards.

ACT is organized to ensure geographic and sector involvement:

- Headquarters is located at the UMCES Chesapeake Biological Laboratory, Solomons, MD.
- Board of Directors includes Partner Institutions, a Stakeholders Council, and NOAA/CSC representatives to establish ACT foci and program vision.
- There are currently eight ACT Partner Institutions around the country with coastal technology expertise that represent a broad range of environmental conditions for testing.
- The ACT Stakeholder Council is comprised of resource managers and industry representatives who ensure that ACT focuses on service-oriented activities.

The ACT workshops are designed to aid resource managers, coastal scientists, and private sector companies by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of new sensors and sensor platforms for monitoring, studying, and predicting the state of coastal waters. The workshop’s goal is to help build

consensus on the steps needed to develop and adopt useful tools, while facilitating critical communication among the various groups of technology developers, manufacturers, and users.

ACT Workshop Reports are summaries of the discussions that take place between participants during the workshops. The reports also emphasize advantages and limitations of current technologies while making recommendations for both ACT and the broader community on the steps needed for technology advancement in the particular topic area. Workshop organizers draft the individual reports with input from workshop participants.

ACT is committed to exploring the application of new technologies for monitoring coastal ecosystem and studying environmental stressors that are increasingly prevalent worldwide. For more information, please visit www.act-us.info.

GOALS FOR THE WORKSHOP

The Alliance for Coastal Technologies (ACT) workshop titled “Enabling Sensor Interoperability” was hosted by the Gulf of Maine Ocean Observing System (GoMOOS) in Portland, Maine from the evening of Monday, October 16 through the morning of Wednesday, October 18. A cross-section of the ocean observing community, consisting of operational managers, industry representatives, and researchers, was invited to attend.

This ACT workshop had four major goals:

1. Summarize the existing technologies for instrument interoperability in observing systems.
2. Identify what is needed for observing systems to realize instrument interoperability.
3. Identify the barriers and challenges that exist to achieving instrument interoperability.
4. Recommend a series of actions to overcome these barriers.

For the purpose of the workshop, participants spoke in terms of “instruments” rather than “sensors,” defining an instrument as a device that contains one or more sensors or actuators and can convert signals from analog to digital. This working definition enabled participants to discuss interoperability at levels above basic measurement and minimized the semantic confusion associated with some definitions of “sensor.”

There are multiple definitions of sensors available (see for example <http://marinemetadata.org/sensordefs>). The American National Standard T1.523-2001 defines a sensor as “a device that responds to a physical stimulus, such as thermal energy, electromagnetic energy, acoustic energy, pressure, magnetism, or motion, by producing a signal, usually electrical.”

ORGANIZATION OF THE WORKSHOP

The workshop commenced with a reception and dinner on the evening of October 16. After a welcome and brief introduction to the goals of the ACT workshops by the CEO of GoMOOS, Philip Bogden, a keynote presentation was made by Jeff Burch of Agilent Technologies, Inc. The talk, entitled “Lessons from Distributed Measurement and Control Applications at Agilent Laboratories,” related the speaker’s perspective on the utility of three standards: IEEE 1451, Java Distributed Data Acquisition and Control (JDDAC), and LAN Extensions for Instruments (LXI). He demonstrated a plug and play system that made use of cell phone technologies by running Java code in the embedded cell phone operating system. To help enable a plug-and-work capability for oceanographic instruments, he advised participants to implement something comparable to Transducer Electronic Data Sheets (TEDS). TEDS, part of the IEEE 1451 family of standards, is a format that allows an instrument to be self identifying/describing.

The second day consisted of an introductory plenary followed by three rounds of breakout discussions. After Philip Bogden specified the purpose and goals of the workshop, a speaker from each general class of participants gave a brief overview of their experience with the topic of instrument interoperability.

Tom O’Reilly, of the Monterey Bay Aquarium Research Institute (MBARI), presented his perspective as a researcher (software engineer) who helped develop the Programmable Underwater Connector with Knowledge (PUCK) and its simple command protocol. This approach was designed to enable plug-and-work interface capabilities for RS-232 instruments by providing standardized interfaces to data storage on even existing instrumentation. It has been demonstrated on MBARI’s ocean observing system and is one solution under discussion by the Marine Plug-and-Work Consortium discussion group.

Scott McLean, of Satlantic, Inc. and WETSAT, Inc., followed with a presentation on his perspective as an instrument manufacturer who helped develop the Data Acquisition and Control Network (DACNet) and the Scientific Instrument Interface Module (SIIM) to collect, process, and manage observing system data. He related the nature and history of the instrument industry and observing systems, the characteristics of instruments produced, and addressed why the issue of instrument interoperability has become so important. The speaker advised participants that in order to enable instrument interoperability there must be an ability to uniquely identify instruments and to provide mechanisms that can describe data structure, convert to engineering units, provide a time stamp for measurement data, and process instrument commands. One of the methods for achieving instrument interoperability, implemented at the manufacturer level by Satlantic and WETSAT, is the use of XML metadata to describe both instruments and observing system infrastructure.

The final speaker, Regina Moore, a representative of the National Data Buoy Center (NDBC), gave a presentation from an operational management perspective on the benefits and obstacles to achieving instrument interoperability. While the ability to seamlessly install and relocate instruments throughout NDBC platforms would result in a significant reduction in operational costs and

higher quality data, major funding to overcome many years of unique hardwiring and stop-gap software solutions is lacking.

Breakout Session # 1

Three breakout groups, one consisting of researchers, another of industry representatives, and a third composed of operational managers, were all tasked with answering the following questions:

1. What is instrument interoperability?
2. What standards bodies or standards processes are in use?
3. What methodologies can be used to communicate standards across all stake holders?
4. What types of technologies have been implemented that improve instrument interoperability?
5. What steps would have to be taken to implement each element of interoperability?
6. Others?

Group leaders presented results in a plenary that followed.

Breakout Session # 2

Three breakout groups, each comprised of participants from all three sectors, were then tasked with answering a set of questions that developed out of the first breakout session:

1. What are the key elements of instrument interoperability?
2. What are the barriers to achieving instrument interoperability?
3. How might these barriers be overcome?

Findings were again presented in plenary by group leaders.

Breakout Session # 3

To independently prioritize a list of barriers to instrument interoperability that was derived from breakout session #2, participants separated themselves into two groups, choosing to look at the issue from either an operational or research point of view. An operational-driven system was described as one that requires minimal feedback into the system, while a research-driven system was described as one that requires dynamic command and configuration capabilities. This breakout continued through the end of the day.

Breakout Session # 4

The following morning, group composition was maintained for a final breakout session. Groups were instructed to outline a plan to implement instrument interoperability by organizing tasks

into two parts: those that could be achieved within the next 3-6 months, and those that could be achieved within the next 5 years.

After group leaders reported the findings for breakout sessions 3 and 4 in plenary, a general discussion ensued. Due to time constraints, it was agreed the steering committee would 1) develop a draft list of the recommendations, 2) solicit input from participants on the draft list (by email), and then 3) redistribute this list to the participants for a vote. As planned, the results of that vote were used to prioritize the list of recommendations for this report.

BACKGROUND INFORMATION

The practice and purpose of ocean monitoring has changed considerably over the past 50 years. The initial use of electronic instruments by aquatic scientists in the field began with relatively simple instrument-to-computer connections, made for the purpose of retrieving *in situ*-collected measurement data. Later, when technological advancements enabled the continuous presence and autonomous operation of instruments at sea, small-scale observing stations were established. Eventually, the collection of existing stations or the installation of new sampling arrays became known as ocean observing systems. An increase in the number, scale, and diversity of these systems has evolved to a point where the successful operation of an instrument often requires a number of steps between the measurement and the end user.

Until recently, manufacturers producing instruments were small organizations specializing in particular products and dealing with a small number of customers. Many of the traditional instruments that are still in use today typically use serial interfaces for communications, have low power requirements, provide only raw data, and are designed for less than a year of continuous operation. Originally, research institutions were the predominate developers of observing systems; but now, local environmental and community groups, national and international organizations, and various industries are also interested in monitoring the ocean.

Current trends suggest an evolution from passive operational observing, where after instrument deployment the data are simply collected, archived, and displayed, to active research or society-driven observing, which requires dynamic feedback. There is a desire for long term, extremely short term, and large scale monitoring in order to better understand such things as trends in climate change, the propagation of storms and tsunamis, or the advent of a toxic algae bloom. The only way to fulfill this desire is to deploy and sustain thousands of instruments throughout the ocean. Systems required for such a presence are incredibly complex.

We got to this point, in large part, by advancements in computing power and instrument technology and the birth of the internet. Some of the progressions in technology that have led to increased capabilities of ocean monitoring include the use of satellites (for sensing and phone/transmission telemetry), increasing availability of radio frequencies, cellular networks, robotics, solar panels, acoustic/optical/inductive modems, and fiber-optic cables. A variety of instrument platforms now exist including moorings, towers, cabled systems, drifters, gliders, autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), and benthic rovers.

As a result of these advancements, combined with the associated desire and ability to increase resource capacity, the deployment of large-scale cabled observing systems appears more feasible. While a collection of autonomous moorings is often constrained by power and bandwidth, a cabled array has a relatively massive, continuous supply of both. A cabled infrastructure can sustain a large number and variety of instruments and can be managed by use of the internet protocol suite. An example of a region-scaled cabled observing system, soon to begin implementation, is the planned North East Pacific Time-integrated Undersea Networked Experiment (NEPTUNE). This project will outline an entire tectonic plate with power and communication cables in order to provide for a high number of nodes and diverse platforms. Eventually, it should be able to support a network of mobile AUVs, gliders, and benthic explorers.

Due to the rapid and continual evolution of ocean observing systems, stakeholder interests must be continually reconciled. Now that a great number and variety of systems are operational, combinations of systems are being sought, eventually to become part of one large global “system of systems” (GEOSS). The Ocean Research Interactive Observatory Networks (ORION) program was formed to coordinate and facilitate the development and integration of observing systems. Implementation/management (Integrated Ocean Observing System- IOOS) and research (Ocean Observatories Initiative OOI) initiatives are pushing forward cabled observing systems. While the successful implementation and management of a system implies a minimization of cost and risk, a high level of both is usually required for sustaining break-through research.

The automation of certain tasks has become essential due to the sheer number and complexity of instruments and instrument suites, man power issues (time costs, human error), and the need for a certain level of autonomous operation for such things as system maintenance, diagnostics, event response, and agile coordination between instruments. Since there is no standardization at the level of instrument firmware, “middleware” software has been required to fill this vital role. Middleware must rely on the instrument interface and metadata to manage observing system resources (power, bandwidth, data management), coordinate activities, and perform diagnostics.

A basic level of instrument interoperability, a “plug-and-work” capability between ports, platforms, and observing systems, would benefit all stakeholders (2006 ACT report: *Seabed Sensors*, 2004 NSF report: *Sensors: Ocean Observing System Instrument Network Infrastructure*, and 2003 NRC report: *Enabling Ocean Research for the 21st Century*). To achieve this, there must be some form of standardization for the instrument interface, metadata format, and middleware software. However, there is currently a lack of standards or standards bodies that address this issue.

KEY ELEMENTS NEEDED FOR INSTRUMENT INTEROPERABILITY
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IEEE has defined interoperability as “the ability of two or more systems or components to exchange information and to use information that has been exchanged.” Instrument interoperability spans the entire spectrum of ocean observing, from measurement to end user, by enabling the flexible collection and exchange of various instruments and their output within and across ports, platforms, and systems.

Three key elements of instrument interoperability—the physical, communication, and application layers—are bound together by a set of logical operations. The physical connection, port configuration, driver and application installation, data acquisition, and instrument control processes must be simple for the operator and transparent to the end user. Given an identical environment, an operator must be able to take an instrument from one ocean observing platform, install it on another, and get the same results. For complete interoperability, instruments that use different methods to measure the same variable should return identical answers. This should be achievable without disrupting other elements of interoperability, requiring hardware modification, or the manual installation of software.

An easily performed, robust connection must be made between the instrument and the rest of the observing system structure in order to power the instrument and provide a communications linkage. Compatible connectors are required for this hardware interface, and in some cases, such as with AUVs, this connection must be attainable underwater. While the observing system must be able to manage resources in an effective manner in order to provide an appropriate level and consistency of power and telemetry for each instrument, instruments must adhere to one or more power and communication standards to make this possible.

Once essential power and bandwidth requirements have been met, a common, low-level communications protocol must be available for facilitating information exchange between the instrument and the observing system. For example, an instrument that uses RS-232 must be able to communicate the basic baud rate, bit, and flow control information that is necessary for port configuration and data exchange. For the purpose of the workshop, participants generally assumed this level of communications was readily achievable and primarily focused on higher level application and logistics issues.

To receive data from an instrument (1-way communication) and provide for remote command and control (2-way communication), applications and drivers must be automatically installed at the appropriate interface(s) between the instrument and the end user. This facilitates platform, node, or shore side processing/buffering/archiving of instrument data and provides the higher level of exchange that is necessary for remote updates (of firmware, sample rate, etc), diagnostic testing, and service discovery. For this to occur automatically, it is fundamentally important that an instrument can be uniquely identified and associated with basic attributes, such as the manufacturer/model/serial number/power requirements, in a way that can be discoverable by the use of a standard method.

Information that identifies an instrument and its attributes is referred to as metadata (data about data). Metadata should be stored on the instrument firmware or, at the very least, a universally unique identifier (UUID) must be provided so attributes can be retrieved from some other location. For complete interoperability, in addition to basic identification and temporal (start time, end time) and spatial deployment information (x, y, z), there must also be a set of standard metadata descriptions for the method of measurement, data structure (parsing information), calibration coefficients, measurement statistics, unit conversion, instrument state and health, and alarm features. The downside of only providing a UUID for an instrument would become clear if an operator needed to connect an instrument but had no ability to use the internet for locating the associated requirements and attributes.

There must also be mechanisms for data and metadata interoperability. To achieve autonomous operation and end-user control, data and metadata formats must be especially well-defined, as system operators and science users must be able to send/receive/interpret data and coordinate actions on the fly. This level of 2-way communication requires an accurate observing-system-wide method for time distribution so there can be a coherent interpretation of a variety of measurements, as well as for the concise coordination of time-sensitive sampling activities, such as those required for event response.

Once a standard method of discovery has been used to locate instruments and associated metadata, there must be a standard way to express available services for prospective measurement or retrospective analysis. From this expression, a standardized collection of observing system products can then be made. Finally, to enable user access and control, a standard service operating model must be able to support a sufficient body of operator and end-user applications, and a complete set of instrument control commands must be provided.

The following summary identifies the elements of interoperability, from the perspective of an end user:

- To engage end users, there must be a sufficient body of applications available for use.
- To provide a sufficient body of applications, there must be an interpretable, comprehensive collection of observing system products, whether prospective or retrospective.
- To collect observing system products, there must be a standard expression of available services, for prospective measurement or retrospective analysis.
- To express available services, there must be a way to discover what measurements are being or can be made.
- To discover what measurements are being made, there must be a standard method for identifying instruments uniquely and to tell which measurements can be made, or have been made, by each instrument.
- To identify instruments uniquely by use of a standard method, each must have a community-agreed UUID.
- To generate community-agreed UUIDs, there must be a community consensus that UUIDs are important.

EFFECTS OF A LACK OF INSTRUMENT INTEROPERABILITY

The expansion of observing systems and the diversification of instruments and platforms have revealed several characteristics that are symptomatic of a lack of instrument interoperability. A lack of scalability, extensibility, and portability are ultimately seen in poor data quality and high cost. The major sectors of the ocean observing community (researchers, manufacturers, observatory operators, and system of system architects) are directly affected by these problems and recognize the need to enable instrument interoperability.

Scalability and extensibility are issues related to the number and composition of instruments in an observing system. Scalability is the ability of a system to increase the number of instruments and platforms without overloading capacity. A system is not readily scalable if attempts to add instru-

ments result in an increase in the percentage of communication and power failures. Extensibility is the ability of a system to smoothly adapt to changes in the types of instruments, platforms, and physical configurations. An example of a lack of extensibility would be an increasing need to replace or make fundamental revisions to entire platforms or operating systems in order to accommodate new instrumentation.

Portability is the ability to move instruments between ports, platforms, and observing systems without requiring a significant effort for the transportation, installation, configuration, or attainment of instrument control. Problems associated with the movement of instruments between platforms could result in the disruption of other elements of interoperability, the requirement of hardware or software modifications, or the manual installation of manufacturer-specific software. When instruments can be seamlessly installed or relocated, the operator has a level of flexibility that ultimately results in higher quality data and reduced cost.

While a reduction in data quality can have many sources, the increase in cost can often be attributed to expensive ship time (to deal with instrument failures, data degradation, update issues, etc.) and personnel cost (to keep track of instrument information, install new hardware and software, provide a multitude of training in order to keep up with disparate requirements, etc.). All these costs can be mitigated with highly interoperable system components.

Effects of the lack of instrument interoperability span the entire spectrum of ocean observing, from the measurement to the end user. Researchers are not getting all the data they want, manufacturers are missing out on part of the market, observing system operators are desperately trying to manage cost, and system of system architects are finding that integration of systems and data sets is far from straight forward. In addition, advanced sampling methodologies, such as peer to peer networking for autonomously coordinated event response, will be difficult to implement until factors responsible for the above described symptoms have been identified and overcome.

BARRIERS AND CHALLENGES TO ACHIEVING INSTRUMENT INTEROPERABILITY

To independently prioritize a list of barriers to instrument interoperability that was identified during the workshop, participants separated themselves into two groups, choosing to look at the issue from either an operational or research point of view. An operational-driven system was described as one that requires minimal feedback into the system, while a research-driven system was described as one that requires dynamic command and configuration capabilities. Three obstacles that both groups placed a high priority on overcoming included the lack of:

1. A registry for instrument identification and attributes
2. Stakeholder engagement
3. Funding

Registry for instrument identification and attributes

There is no mechanism in place to require or provide accommodations for the registration of an instrument and its associated metadata. Ideally, basic information about the manufacturer, model, serial number, and owner would be registered by the time of the first deployment and would get added to and updated regularly over the course of an instrument's lifetime. This database could be accessed every time an instrument is redeployed in order to facilitate the installation process (providing configuration requirements, drivers, etc.). Potentially, one could query the database and determine when and where an instrument was previously deployed, what platform it was deployed on, what repairs or other services or upgrades were made, what the calibration coefficients were for a given period, where the data is stored, etc.

Stakeholder engagement

To enable instrument interoperability, there must first be a collective recognition of the problem and an interest in overcoming it. When individual stakeholders are focused on making their instrument/project/system work, it can be difficult to focus on higher levels of abstraction. If only a handful of stakeholders got together and tried to address the issue on their own, a number of potentially effective strategies may develop, but the implementation of these ideas across all sectors would be difficult to achieve.

Funding

Currently, there is a lack of funding for meeting some of the basic requirements that would help move the community toward instrument interoperability. Funding cycles of 2-3 years do not allow for considerable reinvestment. For example, the replacement/upgrade of analog instrumentation or the development of a test-bed facility would take significant up front costs.

Additional obstacles of high priority, from the operational perspective:

- There is no standard schema established for defining the structure of data and metadata.
- There is no well-defined discovery process for resolving basic power and communication issues.
- A significant commitment of time must be made in order to develop instrument interoperability standards.

Additional obstacles of high priority, from the research perspective:

- There is no standard method for providing/installing all of the necessary drivers between instruments and observing system applications.
- Lack of a common set of commands for instruments makes it difficult for an observing system to establish a basic level of control.
- The fact that there is no canonical block diagram that presents an architecture of the instrument environment, including the instrument and associated middleware and user interfaces, inhibits clear discussion on the subject of instrument interoperability.

Additional obstacles identified:

- No standard approach exists for overcoming legacy issues such as analog instrumentation.
- There is a general lack of a systems perspective in the community.
- There is a tremendous disparity in user requirements.
- A lack of vendor buy-in makes it difficult to enforce standards that would breed competition.
- No organization has a funded mandate to define instrument interoperability for ocean observing systems.
- There is a perception that standardization of instrument interoperability is not economically feasible.
- Decades of local hardwired and software solutions (“stove piping”) has led to infrastructure and institutions that are unable to swiftly adapt to new circumstances or develop the strategies necessary for enabling interoperability.
- Proprietary issues can inhibit the exchange of information and ideas that must occur in order to enable instrument interoperability.
- A lack of a common language, a semantic infrastructure that would help enable interoperability, presents a challenge for discussion (i.e., a working definition for “instrument” had to be determined at the beginning of this workshop).
- The current level of dialogue within and across the platform community is not sufficient.

<p style="text-align: center;">SUMMARY OF ADVANCEMENTS IN TECHNOLOGY AND STANDARDIZATION BASIC SUPPORT FOR INSTRUMENT INTEROPERABILITY</p>

Since the initial deployment of ocean observing systems in the 1960s and 1970s, advancements in technology and standardization have significantly increased the capacity for data acquisition and instrument control. Improvements at the physical, communication, and logical levels, and the development of “smart” transducers have provided much of the basic support required for instrument interoperability.

Advancements at the Physical Level

The ability to acquire data has been significantly improved by advancements at the physical level. Submersible connectors have become more robust over the years, with military standards (MIL-STD) often leading the way. Fiber optic cables are now present across parts of the ocean floor and much of the continents. Meanwhile, breakthroughs in wireless communications standards, such as IEEE 802.11 and those of the ZigBee Alliance, are helping to eliminate much of the local cable infrastructure (reducing cost and complexity) within nodes, between instruments, and in node-to-shore telemetry. Analog to digital interfaces, starting with the modem and now integrated into a variety of devices such as personal computers and cell phones, provide a more efficient transfer of information and help to reduce cross-talk.

Advancements in Communication

Communication standards that facilitate data acquisition include the use of serial connections, especially RS-232, but also including SDI-12, and, more recently, the development of RS-422, RS-485, and the Universal Serial Bus (USB). Many people believe that RS-232 and other serial connections will eventually be replaced by Ethernet. Ethernet standards use a set of protocols that focus on the movement of data, greatly increasing bandwidth. Finally, the internet protocol suite, particularly TCP/IP, has become a robust and adaptable method for information exchange, spawning web services that can help to manage complex systems.

Advancements at the Application/Logical Level

Java and the eXtensible Markup Language (XML) are two of the most widely used programming languages for interfacing applications and transmitting data, respectively. Java, the web-based, object-oriented programming language that was first implemented in 1995, provides a platform for “Write Once, Run Anywhere” applications that can be run on any operating system. The language was constructed to be “architecture neutral, portable, and dynamically adaptable” (<http://java.sun.com>). XML, as described succinctly by W3Schools, is “a cross-platform software and hardware independent tool for transmitting information” (<http://www.w3schools.com>). In many ways, it is the ideal method for storing and processing data because it describes data in a way that is human readable and extensible across many applications.

For plug-and-work capability there must be automatic detection, configuration, and driver and application installation at the moment an instrument is connected to a network. Universal Plug and Play (UPnP) is a five-step protocol for enabling this capability that uses an XML format for data transfer. Another method, Jini, is described as “protocol agnostic,” meaning that it is independent of any other communication protocol. While UPnP makes information directly available and retainable by clients, Java-based Jini is more of a service-based architecture with a centralized service registry. Both of these discovery protocols rely on the use of self-identifying, or “smart,” transducers.

Smart Transducers

As a result of advanced programming languages and the steady increase in computer speed and memory size, software is increasingly capable of managing observing system instrumentation and resources. A natural progression and extension of these advancements in “middleware” is the development and implementation of smart transducer technology. Effectively, this is the migration of middleware capabilities toward the transducer (a sensor or actuator).

Smart transducers that self-identify/describe/organize/calibrate automatically convert raw measurements to engineering units and can be made to perform other sophisticated operations and can also help to improve/promote information exchange between instruments and end users and enable the autonomous operation of systems. The most fundamental trait of being “smart” is the ability to self-identify. Since a transducer typically just takes a measurement or performs an action, the host instrument is often the primary location for this additional intelligence.

IEEE 1451 Standards

The IEEE 1451 family of Smart Transducer Interface Standards provides a set of vendor and network independent universal interfaces between transducers and applications. The various “partitioning” of the general model of a smart transducer is made possible by the use of Transducer Electronic Data Sheet (TEDS), a key concept for every standard within the family.

The TEDS is a method for storing and providing access to the essential metadata that allows a transducer to become self-identifying. There are three parts to the TEDS:

1. *Basic TEDS-*

This 64-bit section is installed in a write once memory that uniquely identifies the transducer by containing the manufacturer ID, model number, version letter, version number, and the serial number. This section is a minimum requirement for implementing any of the IEEE 1451 standards.

2. *Standard TEDS and/or Calibration TEDS-*

This section contains configuration, conversion information, and other essential characteristics of the transducer and can also define three different levels of access to the TEDS memory.

3. *User Area-*

This section allows for additional storage of information by the operator (transducer location, orientation, maintenance history, etc.).

The TEDS can be implemented in a human readable, binary, or XML format stored anywhere between the point of measurement and the instrument, effectively providing a transducer with “smarts.” While the TEDS can be installed in the native transducer memory or on a separately installed Electronically Erasable Programmable Read-Only Memory (EEPROM), a virtual TEDS can be stored at a registry. A virtual TEDS is useful if there is no mechanism for storage or retrieval of information at the instrument level.

IEEE 1451.4 utilizes the TEDS concept to bring intelligence to analog transducers, enabling a plug-and-work capability for legacy instrumentation. This standard separates the transducer and instrument into two components: the network independent transducer module that contains the transducer-to-environment interface (the Transducer Interface Module, or “TIM”), and the network specific host module that contains the instrument-to-internet interface (the Network Capable Application Processor, or “NCAP”). The boundary between the TIM and the NCAP is bridged by use of the Mixed-Mode Interface or “MMI.” A class one MMI uses a switch for controlling analog and digital output, while a class two MMI calls for a completely separate set of wires for digital transmission, allowing for a continuous stream of both output types.

STANDARDS AND STANDARDS-RELATED ORGANIZATIONS

Participants listed some of the standards, standards bodies, and standards projects that seek to improve interoperability.

Standards

- MIL-STD- *U. S. military standards collection (esp. connector specifications)*
- RS-232/422/485- *serial communications*
- SDI-12- *serial communications*
- NMEA 2000- *marine electronics standard (communications)*
- IEEE 802.11- *wireless LAN/WLAN (communications)*
- IEEE 1451- *for behavior and low level measurements (logics)*
- IEEE 1588- *protocol for time synchronization (logics)*
- see <http://marinemetadata.org/content/refs/cssensors> for additional references on sensor content standards

Standards Bodies

- ANSI (American National Standards Institute)
- FGDC (Federal Geospatial Data Committee) - *metadata model for geospatial data collections*
- IEEE (Institute of Electrical and Electronics Engineers)
- ISO (International Organization for Standardization) - *standards for geospatial data models*
- NIST (National Institute of Standards and Technology)
- OASIS (Organization for the Advancement of Structured Information Standards) - *web services, security*
- OGC (Open Geospatial Consortium) - *data models, metadata encodings, web services*
- SEEDS (The Strategic Evolution of ESE (Earth Science Enterprise) Data Standards) - *NASA*
- W3C (World Wide Web Consortium) - *low-level languages and protocols*

Standards Projects

- ACT (Alliance for Coastal Technologies) - *NOAA funded partnership*
- DMAC (Data Management and Communications) - *IOOS*
- DODSSP (Department Of Defense Single Stock Point) - *MilSpecs and standards*
- IODE (International Oceanographic Data and information Exchange)
- JCOMM (Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology)
- LXI (LAN Extensions for Instruments) - *industrial consortium*
- Marine Metadata Interoperability Project
- Marine Plug and Work Consortium
- ORION (Ocean Research Interactive Observatories Network)
- Standards.gov
- USB (Universal Serial Bus) - *industrial consortium*

- XML.Gov
- WMO (World Meteorological Organization)

**SUMMARY OF ADVANCEMENTS IN TECHNOLOGY AND STANDARDIZATION
EMERGENCE OF INSTRUMENT INTEROPERABILITY**

Building on these advancements, an emerging number of protocols, projects, initiatives, and various organizations have recently begun to focus on the implementation of key elements of instrument interoperability.

PUCK implementation of a TEDS-like concept

For instruments that are not “smart,” the concept of a PUCK (Pluggable Underwater Connector with Knowledge) has been developed at MBARI. PUCK allows instrument metadata to be physically attached to an instrument, yet available to the host on a non-interference basis. PUCK is a patented hardware component and software protocol that improves instrument interoperability by enabling plug-and-work compliance for both new and legacy RS-232 instruments. Prior to deployment, the PUCK can be loaded with any information that is necessary to utilize the instrument when it is plugged into an observing system, then accessed by the host—using a special protocol—to download the information. The PUCK does not care what kind of content is downloaded and, as a result, can be used in any interoperability design. (MBARI provides the PUCK patent for use on a royalty-free basis.)

JDDAC implementation of IEEE 1451

As shown by the keynote speaker, JDDAC, an open-source platform developed by Agilent Technologies, Inc. and Sun Microsystems, Inc., has been successfully used to integrate elements of the IEEE 1451 (1451.1 and 1451.2) and IEEE 1588 (time distribution protocol) into a network of instruments that monitor San Francisco Bay (Networked Bay Environmental Assessment and Monitoring Systems- NetBEAMS). In this system, Java APIs are used to connect the end user to the physical world.

Other implementations of interest

DACNet (Data Acquisition and Control Network) was developed by Satlantic, Inc. to manage a variety of ocean observing systems. Central to its success is an XML-based schema for describing instrument metadata that provides plug-and-work capability.

SIAM (Software Infrastructure and Applications for MOOS (Monterey Ocean Observing System)) provides a sophisticated, metadata-aware middleware layer that can handle low-power, intermittently connected platforms, such as buoys.

ROADNet (Real-time Observatories, Applications, and Data-management Network) manages data connections between ships, ship and shore, and as data flows throughout a distributed system.

Sensor Web Enablement

The Sensor Web Enablement (SWE) initiative, conceived by the Open Geospatial Consortium (OGC), seeks to enable discovery, access, tasking, and alert notification of transducers by use of the internet. This is accomplished by developing a set of web services and encodings as open standards. An information component provides models and XML schemas for defining data and metadata encodings, supporting archived, real-time, and streaming data. An especially relevant feature is the SensorML schema, which provides support for plug-and-work instrumentation. A service component defines several web service interfaces that discover and retrieve transducer observations and measurements, enable end-user control, and provide synchronous and asynchronous alerts.

Mechanisms for testing instrument interoperability

In recent years, the interoperability of instruments has also been facilitated by short term initiatives, called “plug-fests,” and the development of permanent test-bed facilities. A plug-fest is the organized collection of component providers for the specific purpose of testing the interoperability of the instruments and software they produce. This process not only promotes the rapid development of solutions, it also provides some of the necessary momentum that is required for the development of long term standardization, promotes communication between stakeholders, and can lead to the vendor buy-in that is ultimately required for standardization to take place. Test bed laboratories have been funded to provide facilities and methodologies for third party testing of the interoperability of instruments. An example of this type of facility is the University of New Hampshire InterOperability Laboratory, which serves as a test bed for data networking technologies.

Organizations that seek instrument interoperability

With the acceleration in instrument interoperability efforts, several organizations in addition to ACT have undertaken activities to further develop community awareness and collaboration. The Marine Plug and Work discussion group (<http://www.mbari.org/pw>) targets the development of standards and practices for transducer interoperability and anticipates forming an independent consortium to pursue these goals. The Marine Metadata Interoperability Project (<http://marinemetadata.org>) has a collection of sensor-related standards referenced on its site and recently hosted a Sensor Metadata Interoperability workshop (see Box 2), in coordination with the ACT workshop, to pursue interoperable sensor descriptions.

SENSOR METADATA INTEROPERABILITY WORKSHOP
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The Marine Metadata Interoperability (MMI) project also held a workshop in Portland, Maine during the week of October 16. The Sensor Metadata Interoperability (SMI) workshop focused on the interoperability of sensor descriptions. Synergy between the two workshops was intentionally sought by this scheduling, and 12 people attended both workshops.

The SMI workshop identified multiple areas where ACT could potentially help to implement key elements of sensor metadata interoperability. Three especially relevant recommendations were:

- “A common data model should be developed in the Unified Modeling Language (UML) to represent the data aspects of IEEE 1451, TransducerML, and SensorML. Goals of the data model are to come to a concrete understanding of what each specification incorporates in its model and to represent those contents uniformly in UML.”
(ACT could help create this model.)
- “Create a sensor description registry for storing descriptions of sensor models (from manufacturers or system developers).”
(ACT might serve as a good organization to host such a repository.)
- “Determine if there is a clear direction to proceed with manufacturers to offer their specifications in a standard way. Use the common data model and sensor description registry as appropriate.”
(ACT could work with manufacturers to facilitate this process.)

There were a number of other specific approaches and tasks identified during the SMI workshop that could benefit from ACT participation, some of them overlapping with recommendations of this report. (The two workshops, and their reports, are entirely complementary.) We have published all of the relevant recommendations from the SMI Workshop Report in Appendix F. ACT and MMI are continuing to discuss the potential collaborations from the two workshops.

GENERAL APPROACHES FOR ACHIEVING INTEROPERABILITY

Some form of standardization would expand the market and help bring about the implementation of essential elements of interoperability. There are four major approaches that could be taken separately or in combination in order to facilitate the process: an informal adoption of existing standards, the creation of new standards, a community-wide agreement/certification process that would be self-enforcing, and/or a large program that demands the interoperability of supplier instruments. However standards are determined, they should not impede the diverse needs of observing systems and instrument manufacturers and must be effectively communicated across all stakeholders.

Informal adoption of existing standards

There should be an evaluation of the currently successful interoperable systems by interested members of the community. If possible and appropriate, elements of existing standards could be informally adopted. For example, IEEE 1451 Transducer Electronic Data Sheets (TEDS) may be a useful model for providing basic instrument metadata. The community-wide adoption of a standard software schema could also help to improve both instrument and metadata interoperability.

Creation of new standards

During standards creation, community interests should be solicited for additional input, and end user advisement would be especially helpful. The rapid development of a minimal standard could start as a limited-use case and require responsible people at each level, providing the momentum required for meeting the goals of instrument interoperability.

Community-wide agreement/certification process

By organizing a set of stakeholders that appreciate the need and value of interoperability, a process could be initiated that would identify community needs, enable the development and testing of standard prototypes, and possibly lead to a series of recommended adoptions. A certification process could be used to identify participants who have informally adopted these standards.

A major project could drive instrument interoperability

Existing programs could be given additional funding to meet the challenges of interoperability, or a new organization could be formed to act as the supporting funding agency for interoperability implementation. A large program that demands interoperability from its instrument suppliers could also help increase the level of cooperation between vendors. At the very least, large funding providers should be encouraged to promote essential elements of instrument interoperability whenever possible.

Key points:

- The interface between instrument drivers and observing system processing is especially important.
- There should be a clear demonstrable benefit for small scale or unconventional observatories to buy into the idea of using a set of formal or informal standards/protocols so that short term solutions will be discouraged.
- Stakeholders must be engaged for the funding necessary to overcome many of the barriers to achieving instrument interoperability.

It is also important to emphasize that the process of overcoming the obstacles to achieving instrument interoperability might be facilitated by identifying a common goal (or set of goals) for ocean observing systems. If all sectors involved in the process (researchers, manufacturers, managers, system of system architects, and any other group with an interest in aquatic monitoring) identified with the goal(s), it could become a significant enabler of instrument interoperability.

METHODS TO COMMUNICATE STANDARDS

Participants agreed that clear communication of standards across all stakeholders is critical and came up with a list of potential mechanisms to help achieve this:

Top-down

- authorities dictating standards
- use of, or creation of, standards bodies
- use of, or creation of, a regulatory agency that would provide incentives and create penalties for non-compliance
- free-market encouragement
- a national repository for instrument information

User Level

- good venues for communication, such as workshops
- active outreach into user communities
- demonstrations of instrument interoperability solutions
- educational institutions could provide trainings and graduate students
- hands-on experience
- regular meetings of all major stakeholders
- alpha beta trials

Documentation

- websites
- mailing lists
- telemarketing
- formal documents
- presentations
- white papers

IMPLEMENTING INSTRUMENT INTEROPERABILITY

Participants identified a variety of tasks to help implement instrument interoperability. Tasks that can be acted on immediately focused on facilitating communication about the topic, organizing stakeholders for action, developing a knowledge base, and planning an intense workshop to gain initial momentum. Additional tasks, deemed achievable within 5 years, dealt with establishing a standards body, providing outreach, developing a simulation platform, developing other forms of standardization that would help to foster and perpetuate a state of instrument interoperability, and implementing a standard plug-and-work capability for ocean observing instrumentation. While the actual grouping and implementation of these tasks may take on a different form, it is believed the essential elements are included here.

Tasks achievable within 6 months

The appropriate combination of stakeholders should use previously developed interoperability frameworks to define roles and responsibilities, identify areas of potential leverage, limit scope, and prioritize. This stakeholder participation could take the form of working groups that begin articulating the value proposition to the various sectors, develop requirements from a system engineering perspective, and ensure the appropriate leverage and coordinating opportunities are being utilized. The initial charge could include the following tasks:

- Compose and distribute a list of recommendations for enabling instrument interoperability to instrument developers.
- Compose and distribute a list of recommended funding sources to all stakeholders.
- Communicate milestones for achieving instrument interoperability to the appropriate program managers.

- Encourage a provision of funding to develop and demonstrate instrument interoperability technologies involving instrument manufacturers, observing system operators, and cyber infrastructure groups.

A canonical block diagram that presents architecture of the instrument environment, including the instrument and associated middleware and user interfaces, would help to allow the subject of instrument interoperability to be discussed more clearly. In addition, the development of a unified modeling language representation of a block diagram of various interoperability standards could be an effective way to assess potential forms or sources of standardization.

Vendors or other members of the community could organize the first annual (or more frequent?) “plug-fest” for oceanographic instruments in order to develop an interoperable instrument prototype. This type of collaboration/competition could improve the ease of use and quality of instruments, leading to the integration of new/improved technologies into observing systems. A set of guidelines for these events could help to ease competitive fears. A possible way to fund this sort of standardization process model would be to add a marginal cost to the purchase price of an instrument.

Tasks achievable within 5 years

An instrument interoperability standards body could be established to address standards for metadata output at the instrument level, commands, protocols, processes, exclusivity (access rights to data and systems), and naming authorities (an organization that provides guidance for selecting a standardized terminology). Regardless of whether this body is formed, OOI and IOOS could develop instrumentation conformance standards with the help of their stakeholders.

An annual symposium on ocean observing engineering and operations and cyber infrastructure could be established. This kind of forum could help the ocean observing community to continually leverage the brightest minds and latest technology for the purpose of solving current and future problems of interoperability. Characteristics of this symposium might include the presence of computer science graduate student proposals, peer-to-peer networks for fleets of autonomous underwater vehicles, a collection of documents and functional artifacts, and it could follow the Apache model (non-profit, decentralized, open-source software).

The development and maintenance of an online “virtual” laboratory for computer science research could provide a set of both operating and virtual observing system samples for testing algorithms, use case scenarios, and performing other useful simulations. For example, simulations performed on this platform could help develop a strategy for moving current middleware capabilities to the instrument level.

A standard method for coordinating and prioritizing the allocation of sampling space and the delivery of observing system resources (such as power and bandwidth) could be developed through the combined effort of researchers and operation managers in order to minimize the potential for conflict between instruments. A resource that identifies composable instrumentation could be developed to provide the ability to conduct an experiment, allowing instruments to work together for a common purpose.

The following steps would help to implement a standard plug-and-work capability for ocean observing instrumentation and provide for the standardized collection and expression of data and services that could be used by a wide variety of applications (most of these items could probably be addressed within 18 months):

- An algorithm/strategy for generating UUIDs must be agreed on and implemented. A potential model for this may be the methodology used to generate a MAC address.
- A common protocol for the automatic discovery of instruments should be developed in order to facilitate installation and to express services.
- A standard registry and registry method for instrument UUIDs and attributes should be created. This could provide all necessary information required for seamless installation (configuration requirements, APIs), data access (live and archived), and control (basic command sets, etc.).
- Uniform methods for measurements should be sought to facilitate the continued development of standard schemas that allow for the interpretable, comprehensive collection of observing system products.

The implementation of these tasks would not only empower the end user, it would also help grow a broad base of stakeholders who would recognize the value of instrument interoperability and promote its enablement.

RECOMMENDED ACTIONS

Participants outlined a plan to implement instrument interoperability by organizing tasks into two parts: those that could be achieved within the next 6 months, and those that could be achieved within the next 5 years. Recommended actions derived from these tasks were ranked by order of importance (equivalent rank is denoted by + or †).

Achievable Within 6 Months

- +1. A list of recommendations for enabling instrument interoperability should be put together and distributed to instrument developers.
- +2. A recommendation for funding sources to achieve instrument interoperability should be drafted. Funding should be provided (for example through NOPP or an IOOS request for proposals) to develop and demonstrate instrument interoperability technologies involving instrument manufacturers, observing system operators, and cyberinfrastructure groups.
3. Program managers should be identified and made to understand that milestones for achieving instrument interoperability include:
 - a) selection of a methodology for uniquely identifying an instrument
 - b) development of a common protocol for automatic instrument discovery
 - c) agreement on uniform methods for measurements

- d) enablement of end user controlled power cycling
 - e) implementation of a registry component for IDs and attributes
4. Working groups of experts should be formed that can begin to:
- a) start articulating the value proposition for various stakeholders
 - b) develop requirements from a system engineering perspective
 - c) assure appropriate leverage and coordinating opportunities are being utilized
 - d) develop a strategy for moving current middleware capabilities to the instrument level
 - e) if deemed appropriate, take on additional tasks identified by this report
5. A canonical block diagram that presents architecture of the instrument environment, including the instrument and associated middleware and user interfaces, should be developed to allow the subject of instrument interoperability to be discussed more clearly.
6. Vendors should organize the first “plug-fest” for oceanographic instruments in order to develop an interoperable instrument prototype.
7. The appropriate stakeholders should use previously developed interoperability frameworks to define roles and responsibilities, identify areas of potential leverage, limit scope, and prioritize. An example of such prioritization, in descending order of importance, should include (some of these sub-tasks may take up to 18 months to implement):
- a) instrument discovery and identification (self discovery, locating instruments, choosing the appropriate instrument) (*suggested lead- ACT*)
 - b) instrument description (*suggested lead- ACT*)
 - c) data content description (*suggested lead- OGC and/or MMI*)
 - d) control interface description (*suggested lead- ACT*)
 - e) data manipulation/processing/lineage
- †8. A conceptual model of a universal instrument driver that enables a wide variety of current and future applications to have control over instruments should be developed for ocean observing systems.
- †9. A unified modeling language representation of a block diagram of various interoperability standards (i.e. IEEE 1451, Sensor Web Enablement, etc.) should be developed.

Achievable Within 5 Years

1. An ocean observing interoperability standards body should be established that addresses standards for:
- a) metadata
 - b) commands

- c) protocols
 - d) processes
 - e) exclusivity
 - f) naming authorities
2. An annual symposium on ocean observing system engineering and operations and cyber infrastructure should be established. Characteristics of this symposium could include the presence of computer science graduate student proposals, peer-to-peer networks for fleets of autonomous underwater vehicles, a collection of documents and functional artifacts, and should follow the Apache model.
 3. A research program responsible for the development and maintenance of an online “virtual” ocean observing system for computer science research should be established. A set of both operating and virtual ocean observing system samples would be provided for testing algorithms, use case scenarios, etc.
 4. OOI and IOOS should develop instrumentation conformance standards with the help of their stakeholders.
 5. A standard method for coordinating and prioritizing the allocation of sampling space and the delivery of ocean observing system resources such as power and bandwidth should be developed, through the combined effort of researchers and operation managers, in order to minimize the potential for conflict between instruments.
 6. A resource that identifies composable instrumentation should be developed to provide the ability to conduct an experiment and that allows instruments to work together for a common purpose. (For example, findings of a third party test bed could be made available through the ACT “Searchable Technology Database.”)
 7. There should be a development of deployable application logic into and throughout any compliant ocean observing network, accommodating disparate levels of network processing.

SMI WORKSHOP RECOMMENDATIONS

The report published for the Sensor Metadata Interoperability (SMI) workshop also contains numerous recommendations for sensor interoperability, including several that overlap with our own. We have published relevant recommendations from their report in Appendix F. The attendees at our workshop supported the recommendations of the SMI Workshop Report, finding they are consistent with and enhance the recommendations in our own report.

FUTURE ACT ROLE AND ACTIVITIES

ACT can help implement key elements of instrument interoperability by:

- providing a discussion forum on its website for assembling a set of recommendations for enabling instrument interoperability and distributing this information to the developers/manufacturers
- providing a registry for instrument identification and associated attributes
- facilitating the standardization of instrument descriptions
- helping to define a standard control interface description
- providing information that helps to identify plug-and-work and composable instrumentation in its “Searchable Technology Database”

ACKNOWLEDGEMENTS

GoMOOS and ACT extend a sincere thank you to workshop participants for offering their time, effort, and insight on this important issue. A special thank you to the key note speaker, Jeff Burch (Agilent Technologies, Inc.), as well as participants who presented during the opening plenary: Scott McLean (Satlantic, Inc. and WETSAT, Inc.), Tom O’Reilly (MBARI), and Regina Moore (NDBC). This workshop would not have been possible without the logistical efforts of Jodi Clark (GoMOOS) and the direction of the steering committee: Scott McLean, John Graybeal (MBARI), Philip Bogden (GoMOOS), and Tom O’Reilly.

This workshop was supported by the Alliance for Coastal Technologies, a NOAA-sponsored program.

APPENDIX A: GLOSSARY OF TERMS AND ACRONYMS

Actuator- a device that acts on an environment

AUV- Autonomous Underwater Vehicle

Driver- a piece of software that serves as an interface between applications, also known as an Application Programming Interface (API)

IEEE- Institute of Electrical and Electronics Engineers

Instrument- a device that contains one or more sensors or actuators and can convert signals from analog to digital

Metadata- information about data (data about data)

Middleware- software that relies on the instrument interface and metadata to manage observing system resources (power, bandwidth, data management), coordinate activities, and perform diagnostics

MIL-STD- Military Standards

Node- the point at which observing system resources (power and bandwidth) are distributed to one or more instruments

PUCK- Programmable Underwater Connector with Knowledge

Plug-and-work- the automatic installation and use of instruments

Sensor- a device that responds to a physical stimulus, such as thermal energy, electromagnetic energy, acoustic energy, pressure, magnetism, or motion, by producing a signal, usually electrical (American National Standard T1.523-2001)

TEDS- Transducer Electronic Data Sheets (IEEE 1451)

Transducer- either an actuator or a sensor

UML- Unified Modeling Language

UUID- Universally Unique Identifier

XML- eXtensible Markup Language

ROV- Remote Operated Vehicle

APPENDIX B: RELEVANT LINKS

Agilent Technologies, Inc.

<http://www.agilent.com>

ANSI- American National Standards Institute

<http://www.ansi.org>

DACNet- Data Acquisition and Control Network

<http://www.satlantic.com/images/Brochures/Brochures%20New/DACNet%2013Jan06%20VerA.pdf>

DMAC- Data Management and Communications

<http://dmac.ocean.us/index.jsp>

DODSSP- Department Of Defense Single Stock Point

<http://dodssp.daps.dla.mil>

FGDC- Federal Geographic Data Committee

<http://www.fgdc.gov>

GEOSS- Global Earth Observing System of Systems

<http://www.epa.gov/geoss/index.html>

Globus Alliance

<http://www.globus.org>

GoMOOS- Gulf of Maine Ocean Observing System

<http://www.gomoos.org>

IEEE- Institute of Electrical and Electronics Engineers

<http://www.ieee.org/portal/site>

IODE- International Oceanographic Data and information Exchange

<http://www.iode.org>

IOOS- Integrated Ocean Observing System

<http://www.ocean.us/home>

ISO- International Organization for Standardization

<http://www.iso.org/iso/en/ISOOnline.frontpage>

JCOMM- Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology

<http://www.wmo.ch/web/aom/marprog/marprog.html>

APPENDIX B: RELEVANT LINKS (CONTINUED)

JDDAC- Java Distributed Data Acquisition and Control

<https://jddac.dev.java.net>

LXI- LAN Extensions for Instruments

<http://www.lxistandard.org/home>

Marine Plug-and-Work Consortium

<http://www.mbari.org/pw>

MBARI- Monterey Bay Aquarium Research Institute

<http://www.mbari.org>

MMI- Marine Metadata Interoperability Project

<http://marinemetadata.org>

NDBC- National Data Buoy Center

<http://www.ndbc.noaa.gov>

NEPTUNE (Canada & US) - North East Pacific Time-integrated Undersea Networked Experiments

<http://www.neptunecanada.ca/index.html>

<http://www.neptune.washington.edu>

NetBEAMS- Networked Bay Environmental Assessment and Monitoring Stations

<http://www.netbeams.org>

NIST- National Institute of Standards and Technology (IEEE 1451 website)

<http://www.nist.gov>

NMEA- National Marine Electronics Association

<http://www.nmea.org/index.html>

NOPP- National Oceanographic Partnership Program

http://www.coreocean.org/Dev2Go.web?Anchor=nopp_home_page

OASIS- Organization for the Advancement of Structured Information Standards

<http://www.oasis-open.org/home/index.php>

OceanPortal

<http://www.iode.org/oceanportal/more.php>

Ocean.us

<http://www.ocean.us>

APPENDIX B: RELEVANT LINKS (CONTINUED)

OGC- Open Geospatial Consortium, Inc.

<http://www.opengeospatial.org>

OOI- Ocean Observatories Initiative

<http://www.orionprogram.org/OOI>

OpenIOOS

<http://www.openioos.org>

ORION- Ocean Research Interactive Observatories Network

<http://www.orionprogram.org>

PUCK- Programmable Underwater Connector with Knowledge

<http://www.mbari.org/pw/puck.htm>

ROADNet- Real-time Observatories, Applications, Data management Network

<http://roadnet.ucsd.edu>

Satlantic, Inc.

<http://www.satlantic.com>

SDI-12- Serial Data Interface (1200 baud)

<http://www.sdi-12.org>

SEEDS (NASA)- The Strategic Evolution of ESE (Earth Science Enterprise) Data Standards

<http://geoinfo.sdsu.edu/reason/SEEDS.htm>

SIAM- Software Infrastructure and Applications for MOOS

<http://www.mbari.org/moos/siam/siam.htm>

SIIM- Scientific Instrument Interface Module (ports power and control)

<http://www.satlantic.com/images/Brochures/Brochures%20New/SIIM%2013Jan06.pdf>

Standards.gov

<http://standards.gov>

UMLWiki- Unified Modeling Language™ Wiki online resource

http://umlwiki.org/index.php?title=Main_Page

UNH-IOL- University of New Hampshire InterOperability Laboratory

<http://www.iol.unh.edu>

USB- Universal Serial Bus

<http://www.usb.org>

APPENDIX B: RELEVANT LINKS (CONTINUED)

W3C- World Wide Web Consortium

<http://www.w3.org>

WETSAT, Inc.- WET Labs, Inc./Satlantic, Inc. (industry collaboration)

<http://www.wetsat.com>

WMO- World Meteorological Organization

<http://www.wmo.ch>

XML.Gov

<http://www.xml.gov>

ZigBee Alliance (standard(s))

<http://www.zigbee.org/en/index.asp>

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Open Geospatial Consortium, OpenGIS® Interoperability Program Report Discussion Paper, 0621r1 *OpenGIS® Sensor Web Enablement Architecture*, 2006

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Schofield, Oscar and Margaret Tivey, eds., 2005. *Ocean Research Interactive Observatory Networks*, Report of the NSF Workshop held January 4-8, 2004, San Juan, Puerto Rico. 140 pp.

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W3Schools (information about XML): http://www.w3schools.com/xml/xml_whatasp

APPENDIX C: REFERENCES (CONTINUED)

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APPENDIX D. WORKSHOP PARTICIPANTS

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APPENDIX E: DISTRIBUTED WORKSHOP AGENDA

Monday, October 16, 2006

Participants arrive by 5:00 p.m.

4:00 Registration in Lobby and receive meeting materials

(Steering Committee meeting)

5:30 Hors D'oeuvres Reception (cash bar) in the Regency Room at the hotel

6:00 Welcome

Philip Bogden, GoMOOS

Tom Shyka, GoMOOS

7:00 Dinner in the Regency Room located within the Portland Regency Hotel

Opening Remarks – Philip Bogden, Alliance for Coastal Technologies

Keynote speaker: Jeff Burch, Agilent Technologies

Tuesday, October 17, 2006

7:00 Breakfast buffet in the Armory Room at the hotel

8:30 Travel (nice walk or quick cab ride) to GoMOOS office at 350 Commercial St for meeting

9:00 Plenary Session I

9:00 Introductions, meeting objectives – Philip Bogden, GoMOOS

9:10 Brief overview of sensor interoperability initiatives (10-15 minutes)

Research/OOI Perspective – Tom O'Reilly, MBARI

Industry Perspective – Scott McLean, Satlantic

IOOS/Operational Perspective – Regina Moore, NDBC

10:00 Breakout Session # 1 (by sectors)

Three small discussion groups will be formed, divided by sector (industry, research and management) to discuss the current applications of sensor interoperability, and what would need to be done to implement more widespread interoperability. Topics include but not limited to the following:

APPENDIX E: DISTRIBUTED WORKSHOP AGENDA (CONTINUED)

Group 1 Observatory Operational Group - GoMOOS Conference Room

Group 2 Industry Sector – Gulf of Maine Conference Room

Group 3 Research Sector – TD Banknorth Board Room

Initial Questions:

- 1) What is sensor interoperability?
- 2) What standards bodies or standards processes are in use?
- 3) What methodologies can be used to communicate standards across all stakeholders?
- 4) What types of technologies have been implemented that improve sensor interoperability?
- 5) What steps would have to be taken to implement each element of interoperability?
- 6) Others????

11:15 Break

11:30 Plenary Report/Discussion Session Given by Each Group Session Chair

11:30 Resource Managers

11:40 Research Sector

11:50 Industry Sector

12:00 Summarize/itemize major findings of Breakout Session 1

Steering Committee, Brian, Tom

12:30 Lunch Buffet Provided

1:30 Plenary Session II

1:45 Breakout Session # 2

Three new groups with representatives from all sectors will discuss the barriers and problems in implementing sensor interoperability standards.

Specific questions for the groups to address

3:00 Break – Refreshments Provided

APPENDIX E: DISTRIBUTED WORKSHOP AGENDA (CONTINUED)

3:15 Continuation of Breakout Session

Identification of recommendations to address barriers and issues

4:00 Plenary Session III - Discussion of major findings – reports from groups

Summarize/itemize

5:00 Adjourn for afternoon

Brief meeting between steering committee, discussion leaders and facilitators from each group who will provide a one-page summary of points

6:00 Hors D'oeuvres Reception (cash bar) followed by Dinner at the

Old Port Sea Grill located at 93 Commercial Street (within walking distance of hotel)

After dinner is yours to enjoy as you wish!

Wednesday, 18 October 2006

Check out before 9:00 - Storage for luggage available

7:00 Breakfast buffet in the Regency Room at the hotel

8:30 Travel (nice walk or quick cab ride) to GoMOOS office at 350 Commercial St for meeting

9:00 Plenary Session IV: Formulating recommendations on how to move forward

This session will be made up of a facilitator with a panel of the working group chairs (from each sector) leading a group discussion based on committee reports from Thursday October 17, 2006. Identifying the highest priorities and a series of recommendations on how to proceed based on the workshop discussions, including how ACT can help will be developed. Discuss report strategy and timeline.

10:45 Closing statements (Philip Bogden)

Hand out expense reimbursement forms where applicable

Follow up, workshop assessments, final business

11:00 Adjourn

APPENDIX E: DISTRIBUTED WORKSHOP AGENDA (CONTINUED)

Useful Links:

Alliance for Coastal Technologies Website:

<http://www.act-us.info>

ACT Workshop Reports:

http://www.act-us.info/workshops_reports.php

ACT Technology Evaluations:

http://www.act-us.info/evaluation_reports.php

APPENDIX F: RELEVANT RECOMMENDATIONS FROM THE SMI WORKSHOP REPORT

The Sensor Metadata Interoperability (SMI) workshop focused on the interoperability of sensor descriptions. The attendees at our workshop supported the recommendations of the SMI Workshop Report, finding they are consistent with and enhance the recommendations in our own report.

Relevant SMI Workshop Recommendations, posted at <http://marinemetadata.org/examples/mmi-hostedwork/ontologieswork/mmiworkshop06>:

- The workshop strongly endorses advancing interoperability among metadata frameworks, and recommends establishing funding from multiple sources to pursue this effort.
- A common data model should be developed in the Unified Modeling Language (UML) to represent the data aspects of IEEE 1451, TransducerML, and SensorML. Goals of the data model are to come to a concrete understanding of what each specification incorporates in its model, and to represent those contents uniformly in UML.
- Create a sensor description registry for storing descriptions of sensor models (from manufacturers or system developers). Consider (i) whether this should be the same thing as the global repository for descriptions of sensor instances, in which each individual resource could be registered, and (ii) whether this should also register template descriptions (examples) for others to adapt and use. Requirements include:
 - must allow external resources to point to any given sensor description
 - enable feedback to the author of the description instance or the specification
 - must persist sensor model description for a long time

Define requirements and best practices for sensor registries.

- Determine if there is a clear direction to proceed with manufacturers to offer their specifications in a standard way. Use the common data model and sensor description registry as appropriate.
- Create working examples of sensor model descriptions and put them in the sensor description registry.
- Create a feature matrix of specifications. Document key characteristics of content specifications and best practices for their development (e.g., clear, unambiguous definition of all fields; make existing references available).

Point to relevant references on each specification: wikipedia entry, associated vocabularies, “Dummies Guides,” Conceptual documents like UML views of schema, white papers, tutorials, examples of descriptions in specific domains (oceanography, ...), example use cases and application scenarios, User’s experiences with the specifications (e.g., comment boxes/bulletin boards (need promotion), FAQs, additional documentation

Document best practices for filling out content standards. Describe the minimal acceptable fields to fill out in each content specification. (Must balance the desire for low cost of entry against the desire for greater functional interoperability.)

**APPENDIX F: RELEVANT RECOMMENDATIONS FROM
THE SMI WORKSHOP REPORT (CONTINUED)**

- Identify or create content specifications that allow the definition of policy for a given instrument (who can use it, under what circumstances, how they can use it, how products are used or distributed).
- Identify/recommend a system for creating globally unique identifiers to label each of the following resources: sensors; applications; metadata descriptions; data streams; and data sets. Different unique identifier systems may be appropriate for each resource.
- Characterize best practices for creating and maintaining vocabularies (e.g., moderation practices exist and are publicly defined, terms clearly defined, consistent word ordering)

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