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14. ABSTRACT

The US Navy's Unmanned Undersea Vehicle (UUV) Master Plan (April 2000) calls for adopting a more modular design philosophy and the establishment of standards for better integration of future UUV systems. In early 2002, a study team was formed with representatives from 5 Navy laboratories. Existing standards and systems have been examined, as well as soliciting industry input. Six draft standards were generated from this year's effort:

1. UUV Control Architecture and Software
2. Propulsion and Hotel Power Bus
3. Communications Protocols
4. Data Storage
5. UUV CPU backbone Architecture
6. Electrical Connectors

Future efforts may include establishing standards for UUV modules and the development of guidelines for a modular common mission planner. Further industry and academic input is being sought for the further development of these and other standards.

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US Navy Standards and Interfaces Study: FY 2002 Results

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Abstract

The US Navy's Unmanned Undersea Vehicle (UUV) Master Plan (April 2000) calls for adopting a more modular design philosophy and the establishment of standards for better integration of future UUV systems. In early 2002, a study team was formed with representatives from 5 Navy laboratories. Existing standards and systems have been examined, as well as soliciting industry input. Six draft standards were generated from this year's effort:

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6. Electrical Connectors

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INTRODUCTION

In addition to describing the desired signature capabilities for UUVs, the Navy UUV Master Plan [April 2000] advocates standardization of modules in future UUV development efforts. In early 2002, UUV Executive Steering Group (UUV ESG) chartered a study to develop a modular design philosophy and to establish some initial UUV standards. It is believed that standardization, especially for *payloads*, will provide the following benefits:

- eliminate/reduce duplication of efforts among different UUV programs
- better enable the reconfigurable vision of future UUVs
- shared modules/designs would yield reduced development, production, and O&S costs

Objective

For the FY 2002 effort, the objective of the study was to make recommendations for standard electrical, mechanical, and software/architecture interfaces for near- and mid-term future UUV programs. The Core Study team was composed of members from the following organizations:

- Naval Undersea Warfare System Center (NUWC) Newport (Study Lead)
- Johns Hopkins University / Applied Physics Lab (JHU/APL)
- Naval Oceanographic Office (NAVOCEANO)
- Naval Surface Warfare Center Coastal Systems Station (NSWC-CSS)
- Naval Surface Warfare Center (NSWC)-Carderock
- Space and Naval Warfare Systems Center (SSC)-San Diego

Approach

The first step in developing a set of UUV standards included looking at existing systems and standards for common areas. Some of the areas examined included software languages, types of data transfer, communications modalities, control architectures, electrical interfaces, cable configurations, and physical structures and materials. A standards and interfaces survey was developed and industry input was sought and provided via a Federal Business Opportunities solicitation in July 2002. The Government Team filled out the same survey, documenting the design features of Government-owned UUVs. Analysis of the surveys provided input as to both common and disparate features of existing systems, as well as recommendations and insights on future trends.

In addition to the systems approach, applicable existing standards were also examined. Some of the relevant standards included:

NMEA 2000	National Maritime Electronics Association Interface Standards
IEEE 802.22B	Wireless Ethernet
MIL-STD-1399	Interface Standards for Shipboard Systems
JTA-US Army	Joint Technical Architecture
JAUGS-OSD	Joint Architecture for Unmanned Ground Systems
MIL-C-24231	Underwater Connectors
MIL-C-24217	Underwater Connectors

DRAFT STANDARDS

Based on the surveys, six areas were identified for draft standards:

- UUV Control Architecture and Software
- Propulsion and Hotel Power Bus
- Communications Protocols
- Data Formats and Storage Media
- UUV CPU backbone Architecture
- Electrical Connectors

These were developed and submitted to NAVSEA PMS 403 for review in November 2002.

Control Architecture

This Standard is written to provide a "road map" for UUV Control Architecture in the acquisition of the tactical autonomous vehicles. This standard defines a high level system and processor style of architecture required to support platform-independent application software portability. The following key properties of architectures are needed to support the continuum of autonomous tactical vehicles:

Software portability (including application algorithm re-use)

Data portability between heterogeneous platforms

Application interoperability

Implementation transparency

System scalability

Modularity

Reconfigurability

The architecture affects the structure of the systems development and should:

Result in the creation of a "skeletal" system,

Feature well-defined modules, and

Result in a small number of simple interaction patterns.

To meet the architectural needs for the continuum of UUVs an *open, modular, heterogeneous, hierarchical and event* driven architecture is recommended. This style allows maximum flexibility for combing various components including controllers, data busses, sensors and subsystems. Table 1 lists a number of existing standards that support these attributes.

Power Distribution

Standardization of the UUV power distribution structure is a key driver for total system compatibility. The distribution system routes power throughout the vehicle architecture, provides electrical protection, and provides power conversion or conditioning. It is typically composed of a primary bus for high voltage applications such as propulsion and a secondary bus for low voltage applications such as ancillary equipment (i.e. hotel load) operation. Note, however, that power bus breakout for individual applications remains dependent on vehicle power requirements, and final bus structure is ultimately left to the designer's discretion.

This standard attempts to establish common voltage levels for primary and secondary UUV power buses at varying degrees of vehicle performance. It also suggests reasonable ranges for normal direct current (DC) operation characteristics based on MIL-STD-704E for aircraft electric power characteristics. It does not attempt to specify principal methods of power generation, bus layouts, or specific hardware selection which are factors dependent upon mission and operational requirements.

The primary power bus or propulsion bus for the UUV shall have a 28 VDC operating voltage for low propulsion applications, a 100 VDC operating voltage for medium propulsion applications, or a ~450 VDC operating voltage for high propulsion applications. If required by system designers, the secondary power bus or hotel bus for the UUV shall have a 12 VDC operating voltage for low power applications or a 28 VDC operating voltage for high power applications. As a general guideline, the normal DC operational characteristics for the primary and secondary power buses should follow the limits specified in Table II of MIL-STD-704E.

Table #1. UUV Control Architecture Standard

Component	Example		Referenced Standard
Software	Architecture	Describes the functionality necessary to provide portability of computer applications across networks of heterogeneous hardware and software platforms	IEEE STD 1003.23-1998
	Application Software	Common software C/C++ de facto standard Portability	ISO/IEC 14252: 1995 P1003.1a, Draft Standard for Information Technology – Portable Operating System Interface (POSIC) [C Language]
	Application Program Interface (API)		ISO/IEC 14252: 1995) IEEE Std 802.11-1997 Information Technology-telecommunications And Information exchange Between Systems-Local And Metropolitan Area Networks-specific Requirements.
	Software Execution Platform	Embedded RTOS Multi-tasking (VxWorks)	ISO/IEC 9945-1:1966 Information Technology – POSIX [C Language]
Controller	Vendor Specified		
Internal communications bus	Ethernet (100baseT)		IEEE 802.3u; Supplement to ISO/IEC 8802-3:1993, Local and Metropolitan Area Networks: Type 100BASE-T
	Dedicated serial		MIL-STD-1553B Standard for Medium Speed System Network Bus
Processors	Vendor specified		
Backplane			ANSI/VITA 1-1994, American National Standard for VME64

Central Processing Unit (CPU) Backbone

Three bus options are recommended to provide consistency and design flexibility among UUV applications. These include the VME, PC/104-PC/104 Plus and Compact PCI (cPCI) busses. It is recommended that any CPU backbone selected for use on a UUV be compliant with one of the following specifications:

- PICMG 2.0 R3. Compact PCI Core Specification
- PC/104 Embedded Consortium PC/104 Plus Spec Version 1.2 August 2001
- PC/104 Embedded Consortium PC/104 Specification Version 2.4 August 2001
- IEEE 1014-1987
- ANSI/VITA 1-1994
- VITA 1.1-1997

PC/104 computers are commonly used in industry where a compact, rugged PC based processor is needed. If the processing speed, I/O and timing characteristics of PCs are adequate for the application, PC/104 may be the most desirable option due to the following benefits it provides over VME and cPCI:

- Most compact form factor
- Lowest power
- Lowest cost
- Faster access to the latest technology since based on PC platform
- Very rugged
- Many vendors provide widespread support

For those applications where more physical space is available and more processing power and speed is required, VME may be the better option. It provides the following benefits:

- VME is widely used by existing UUV and other military applications.
- VME has a long history of success and reliability in military applications and is supported by more vendors than competing technologies such as cPCI.
- VME allows true real-time processing with more interrupts and with interrupt latencies that are orders of magnitude faster than ISA and PCI.
- VME provides more capability for peer multiprocessing, a feature commonly used in military applications.
- Alternative technologies, such as the PCI bus, are faced with the real threat of obsolescence in the near future, while VME is experiencing renewed use.

In conclusion, it is important to note that the VME may not be ideal for all applications, however it may be the best choice if the form factor is compatible with the UUV. The VME or cPCI busses are recommended for larger vehicles, with PC104 as an option, provided that the PC platform adequately supports the processing requirements of the application. For smaller vehicles, where a small form factor is required, PC/104 may be the best or only practical option.

Connectors

The US Navy has two long established specifications for underwater connectors and hull fittings used onboard submarines: Mil-C-24231 and Mil-C-24217. These designs are proven for its ruggedness and reliability. However, its size was much too large on space-constraint UUV. Several underwater connector manufacturers have developed their own derivatives from the above mentioned Mil-Std connectors and successfully implemented on various UUVs. In general, these underwater connectors have similar electrical and mechanical requirements to the dry connectors. Moreover, due to the exposure to external water pressure, the underwater connectors shall have environmental requirements to withstand the underwater pressure at different operating depth requirements, and also on material for connector shells and bodies to prevent cathodic reaction on dissimilar materials.

This Standard DOES try to establish specific requirements for the selection, and quality programs if military standard connectors cannot be used. This Standard DOES NOT attempt to specify the areas:

- Electrical: number of contacts or fibers, insulation resistance, voltage or current rating. The u/w connector for fibers is addressed separately, and can be found under 'Fiber Optic Underwater Connector Standard'.
- Mechanical: insert arrangements, material used on the connector body, insert, shell or contacts.
- Environmental: depth rating (open-faced)

Wet connectors: Recommendations include:

- Recommend redundancy (25-50%) on number of conductors or fibers.
- Use separate connectors to separate radiated signals per MIL-STD-461.
- Open-faced rating should be used on selecting an underwater connector.
- The material specification, for the connector housing or shell, must be suitable for underwater pressure ratings of >2,000psi.

Fiber Optic Connectors: Recommendations include

- Follow Mil-C-83522 as a guide, for fiber-optic connector standard
- It must accept the most common multi-mode (62.5/125 micron) and/or single mode (9/125 micron) fiber sizes.
- Optical Contact attenuation for standard wavelengths should be<1.0 db@ 850 nm, 1300 nm, 1310 nm, and 1550 nm.

Dry connectors: Recommendations include:

- Mil-c-81659 or similar rectangular blind-mateable connectors (ARINC-404/600) should be utilized between hull sections, when possible, for ease and reliability of connection. These connectors support copper, coax, and fiber.
- Mil-dtl-38999 or equivalent is recommended internal the UUV pressure hull. This specification supports copper, coax, and fiber. For power applications, Mil-dtl-38999 accommodates to contact size 10. Mil-c-5015 series or equivalent is recommended for power connections, especially for current requirements necessitating a larger contact size.
- Number of connectors: the UUV should keep connections to a minimum for ease of module mating/separation.
- Pin allocation: the UUV shall separate power from data and high level signals from low level signals on connectors.
- Spares: 25-50% extra pins per connector, where appropriate, is recommended.

Data Formats and Storage Media

UUVs collect data on ocean properties as an essential part of their operation. Much of this data must be available on board for use in operations such as maintaining operating depth or navigating. Full data sets are needed for post mission analysis and mission reconstruction, as well as for ocean forecasts for planning future missions. The data format establishes essential items of oceanographic data and metadata. It notes where standard DoD formats are established and where de facto commercial formats exist and are adequate. Data formats should conform to existing usage to facilitate data processing and use.

Temperature and Salinity. These are expected to be point measurements at the UUV depth rather than profiles. Averaged data are not expected. The only absolute data format requirement is that the format in which the measurement value, resolution or precision, and latitude, longitude, depth and time are written be known and provided in plain text with any data set.

Currents. Depth-differentiated ADCP vector profiles are needed, not just reference-layer (speed-log) velocities. Whenever possible, UUVs should be deployed with the depth-differentiated capability of the ADCP enabled in addition to the reference-layer measurements used for UUV navigation. For most ADCP sensors, vehicle speed and heading information can be input from the vehicle's navigation system to transform the current vectors from vehicle-referenced to geo-referenced. If such navigation information is not merged in the field, the vehicle's navigation files must be provided as part of the ADCP data set. For environmental characterization, ADCP profile ensemble times should be between 2 and 5 minutes. Ensemble times of one minute or less result in data that are too noisy. Four-meter depth bins are preferable, but different bins can be used if they are needed for the mission.

Bathymetry: Generic Sensor Format (GSF) supports both single-beam and multibeam bathymetry data. GSF was developed for use as an exchange format in the Department of Defense Bathymetric Library (DoDBL), one of three DoDBL processing formats.

Sonar: The UNIfied Sonar Image Processing System (UNISIPS) is a collection of programs that support post-acquisition processing of these data. It supports common commercial formats. The Mine Warfare (MIW) Environmental Decision Aids Library (MEDAL) directly ingests UNISIPS output.

Optical: MIL-STD-2500B National Imagery Transmission Format (Version 2.1) for the National Imagery Transmission Format Standard.

Electronic Signals: Review of existing and evolving data format standards is underway. Recommendations for adopting standards in this area will be addressed in the near future.

Communications

The objective of the Communications Standard is to establish some basic communications interfaces for US Navy unmanned undersea vehicles (UUVs). With the wide range of communication modalities available (Table 2), it is critical that the UUV be able to operate within the existing communications infrastructure. This is of particular importance for a multi-mission system and / or those to be deployed from a variety of platforms. The vehicle must be able to communicate with the host platform as well as sending data on the path to the eventual user. It also must be compatible and not interfere with other systems resident on the host platforms, particularly in regards to electromagnetic interference and compatibility. The goal is to provide for communications interoperability so that UUVs can be a functional part of the net-centric battlespace.

Line of Sight Communications: The existing large infrastructure of UHF communications equipment provides the easiest path for near term system implementation. Most of the current systems support digital data services and easy connectivity to computer workstations. Most of the equipment will support data rates of 16 kbps, which will allow some product off load, and is more than sufficient for command and control. There are several drawbacks to UHF systems. The biggest drawback to UHF is that it is narrow band. They are not generally connected to exploitation systems or network services. Also, in general, a major drawback to any line of sight system is that the low UUV antenna height restricts the range.

For UHF LOS the following standards apply:

> MIL-STD-188-243 Tactical Single Channel (UHF) Radio Communications, 15 March 1989. This is the basic compatibility requirement for military UHF equipment.
>
> MIL-STD-188-220CInteroperability Standard for Digital Message Transfer Device (DMDT) Subsystems, 22 May 2002. This describes the means and methods for providing data transfer over UHF circuits.

The Common Data Link (CDL) Specification has been mandated by OASD/C3I (13 December 1991) as the DoD standard for airborne ISR platforms. This is also reiterated in the Joint Technical Architecture, v4.0, 17 July 2002. The infrastructure for CDL is growing at a rapid pace as Unmanned Air Vehicles transition from ACTDs to fieldable systems. The UUV community will leverage off of this developing infrastructure. It will provide wide band connectivity to command and control systems and support product offload and delivery to exploitation systems.

Beyond Line of Sight Communications: UHF military SatCom provides worldwide coverage between 70N and 70S and allow access to a number of military messaging systems. Many small UHF radio sets implement both LOS and SatCom modes. Commercial satellite systems provide world wide coverage, including the poles. EMSS supports dial on demand phone circuits and may be able to provide wide band pipe needed for product offload.

In the future, the Joint Tactical Radio System holds tremendous promise for interoperability and flexibility. Multiple wavefoms will be available in a compact package. It holds out the ability to dynamically link UUVs into a surface network, handling the problem of the vehicle entering and leaving the network, while providing enough bandwidth to offload collected sensor product in a reasonable amount of time. The Multi-Platform CDL standard may also provide a high capacity pipe that could be used for UUV operations. Inter connecting UUVs to UAVs would help overcome the low antenna height horizon limits when talking to surface platforms.

FUTURE EFFORTS

The six draft standards were submitted for Government review in mid November 2002. Future efforts include further review and revision of these standards, as well as the addition areas of establishing standard vehicle modules and development of guidelines for a common mission planner.

Establish Standard Vehicle Modules

The UUV Master plan advocates the standardization of modules for future UUV development, leading to flexible, inter-operable systems. The concept of these "modules" run the full range from system-based to physical / geometric- based to function-based units. Initial efforts are looking toward developing payload modules, in support of multi-mission UUVs. This will be a first step towards developing reconfigurable vehicles, reducing the development, production, and operating costs.

Common UUV Mission Planner

The Navy UUV communities are all faced with systems that run proprietary, incompatible software. This is a significant issue in terms of expanding system capabilities, particularly when there are multiple organizations involved beyond the initial contractor. Currently there is discussion in both the large and small vehicle communities regarding the development of common mission planners, which would address many of the desires for cross-platform modularity. What is unclear, however, is how the large and small vehicle communities would coordinate their efforts.

Summary

The FY 2002 Standards and Interfaces Study has established draft standards for six critical areas: UUV Control Architecture and Software, Propulsion and Hotel Power Bus, Communications, Data Storage, UUV CPU backbone Architecture , and Electrical Connectors. Input is sought from industry and academia for the continued development and refining of these and other potential standards. The development and distribution of these standards is intended to provide guidelines for simplified integration and interoperability of Navy UUV systems and sub systems.

Acknowledgements

The UUV Standards and Interfaces Study has been a team effort, drawing on representatives from the following organizations:

- Naval Sea Systems Command PMS 403
- Naval Undersea Warfare System Center (NUWC) Newport (Study Lead)
- Johns Hopkins University / Applied Physics Lab (JHU/APL)
- Naval Oceanographic Office (NAVOCEANO)
- Naval Surface Warfare Center Coastal Systems Station (NSWC-CSS)
- Naval Surface Warfare Center (NSWC)-Carderock
- Space and Naval Warfare Systems Center (SSC)-San Diego
- Sonalysts

References

The Navy Unmanned Undersea Vehicle (UUV) Master Plan, 20 April 2000, Naval Undersea Warfare Center, Newport, RI.

Draft Standards as of November 2002:

Communications Guidelines for Unmanned Undersea Vehicles

Data Formats and Storage Media

UUV Connector Standards

UUV CPU Backbone Standards

Power Distribution Standards for Unmanned Underwater Vehicles

Unmanned Undersea Vehicle (UUUV) Control Architecture Standard

Table 2: UUV Communication Modalities

	SUBMARINE	RELAY BUOY	SHIP	AIRCRAFT	SATELLITE
Optical	Fiber Optic Free-space Optical	Fiber Optic Free-space Optical	N/A	N/A	N/A
Acoustic	Acoustic	Acoustic	TBD	N/A	N/A
Line of Sight RF	UHF LOS	N/A *	UHF LOS	UHF LOS	N/A
Beyond Line of Sight RF	N/A	N/A*	N/A	N/A	UHF SATCOM