

UNMANNED UNDERWATER VEHICLE (UUV) INFORMATION STUDY



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Unmanned underwater vehicles (UUV) are any vehicles that are able to operate underwater without a human occupant. Smaller and cheaper autonomous underwater vehicles (AUV) are today very capable and gaining users. Large autonomous underwater vehicles are more expensive but they offer capabilities in some missions and applications that no other platforms can offer.

However, using unmanned underwater vehicles in marine applications provide some challenges such as noisy communication, position uncertainty and the likelihood of robot failures. In addition, standards for data and information sharing are not well defined and, as mature as it is, the unmanned underwater vehicle field is still an emerging sector.

Within the last decade, interest in UUV to be part of specific military, industrial and academic missions and applications have increased due to technological innovation and the evolution of their sensor payload. Missions such as persistent surveillance, anti-submarine warfare, oceanography and mine countermeasure are amongst those where UUV capabilities far exceed those offered by other platforms.

Canada's vast coastal areas could benefit from the introduction of UUVs to perform various roles. On one hand, their use is very cost-effective. On the other hand, they offer persistence and data quality that are not achievable using traditional methods. This usefulness is even more reflected in remote environments, where deploying personnel is a very costly alternatives.

In order to enable the integration of the data and information provided by a UUV it is necessary to have a look in the underlying data and information sharing standards related to them. Achievement of interoperability between multiple national and international agencies is mandatory if one seeks to use the UUV to its full potential in support of the generation of more complete maritime domain awareness.

In addition to interoperability, integration of UUV data and information faces many challenges such as limited communications which result in latency problems. However, requirements analysis for each mission area will likely result in the identification of a trade-off between communications rate and information latency which is acceptable in order to successfully complete the mission.

The objective of this document is to better understand how Unmanned Underwater Vehicle (UUV)-collected data and information may be shared and used to describe the overall maritime situation, thereby providing improved knowledge and improved Maritime Domain Awareness (MDA).

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ASW	Anti-Submarine Warfare
AUV	Autonomus Underwater Vehicles
BAG	Bathymetric Attributed Grid
C3	Command, Control & Communications
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CBRNE	Chemical, Biological, Nuclear, Radiological, Explosive
CCL	Compact Control Language
CONOPS	Concept of Operations
CN3	Communication/Navigation Network Nodes
COP	Common Operating Picture
CSD	Coalition Shared Data Server
CTD	Conductivity - Temperature - Depth
EIEM	Enterprise Information Exchange Model
ELINT	Electronic Intelligence
GPS	Global Positioning System
GSF	Generic Sensor Format
IA	Influence Activities
ID	Inspection/Identification
IEPD	Information Exchange Package Documentation
IEDM	Information Exchange Data Model
IMINT	Imagery Intelligence
IPB	Intelligence Preparation of the Battlespace
ISR	Intelligence Surveillance and Reconnaissance
MASINT	Measurement and Signatures Intelligence
MCM	Mine Countermeasures
MDA	Maritime Domain Awareness
MUS	Maritime Unmanned System
NATO	North Atlantic Treaty Organization

NAVOCEANO	U.S. Naval Oceanographic Office
NIEM	National Information Exchange Model
NIEM-M	National Information Exchange Model - Maritime
NSILI	NATO Standard ISR Library Interface
NURC	NATO Undersea Research Center
OODA	Observe, Orient Decide Act
PFM	Pure File Magic
RMP	Recognized Maritime Picture
ROV	Remotely Operated Vehicles
SA	Situation Awareness
SIGINT	Signal Intelligence
SensorML	Sensor Model Language
STANAG	Standard NATO Agreement
TCS	Time Critical Strike
UAV	Unmanned Aerial Vehicle
UAS	Unmanned Aerial System
UDA	Underwater Domain Awareness
UNISIPS	Unified Sonar Image Processing System
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
XML	Extensible Markup Language

Part 1

Introduction

Unmanned Underwater Vehicle (UUV), sometimes known as underwater drones, are any vehicles that are able to operate underwater without a human occupant. These vehicles may be divided into two categories, Remotely Operated Vehicles (ROV)s, which are controlled by a remote human operator, and Autonomus Underwater Vehicles (AUV)s, which operate independently of direct human input [1].

AUVs are the most complex as they have to rely on autonomous functions since water does not allow radio-frequency transmission, and acoustic transmission does not allow sufficient bandwidth for direct control at a distance. AUVs have gradually evolved, notably with increasing computing power and growing energy density stored on-board. Small sensors, inertial navigation systems, and a required high overall reliability due to little room left for error, have rendered AUVs expensive [2].

The constant improvement of electronics and software has enabled sensors to be smaller and draw less power. Smaller and cheaper AUVs are today very capable and gaining users. Large AUVs, although still expensive, offer very high capabilities for conducting missions that no other equipment can perform [2].

However, using UUVs in marine applications provide some challenges such as noisy communication, position uncertainty and the likelihood of robot failures.

The objective of the call up is to better understand how UUV-collected information may be used to describe the overall maritime situation, thereby providing improved knowledge and improved Maritime Domain Awareness (MDA). The result should be a better understanding of both the information content and the information architecture that supports the data/information that may be obtained from sensors onboard an UUV, and how this information might support MDA.

This document, which is the final report for Call-up 4, is organized as follows :

- Section 2 presents an overview of the missions and applications planned for UUVs and highlights those which appear most promising to pursue in the Canadian context.
- Section 3 presents the data types that are required to support the missions identified.

- Section 4 presents the existing standards for encoding and distributing the data/information produced by the UUV sensors.
- Section 5 presents the practical aspects of UUV data distribution to ashore systems, such as the delay, its impact and the benefits to the overall MDA and required metadata for efficient search and retrieval.
- Section 6 presents the difficulties encountered during the realization of this Call-up and the general conclusion of this document.

Part 2

Applications and missions of UUVs

While their inherent characteristics make them more clearly suited for some applications than others, UUVs can offer capabilities in many areas, particularly in preparation of the battle space in the face of area denial threats that may present undue risks to manned systems [3].

The US Navy identifies five major benefits to using modern unmanned vehicles in maritime surface and sub-surface applications [4] :

- unmanned vehicles are far less expensive to operate and maintain than manned vehicles;
- automated sensors are able to maintain near-constant awareness and coverage of an environment;
- near-constant surveillance means persistence in data collection, enabling a better understanding of long-term behaviour patterns and trends;
- unmanned platforms also promise to improve productivity, as they allow manned platforms to pursue tasks elsewhere;
- unmanned platforms keep human sailors and expensive manned platforms away from danger.

This section presents an overview of the identified mission in which UUVs can play a role and is organized as follows :

- First, section 2.1 presents a review of the applications and mission in which UUVs can play an active role;
- Section 2.2 then presents the potential of using UUVs in a Canadian's context.

2.1 Overview of UUV related applications and missions

This section presents an overview of the different applications and missions where UUVs can support or conduct a mission. Nine areas were identified in [3] and have since always been used as reference in other publications ([5], [6]):

1. Intelligence Surveillance and Reconnaissance (ISR);
2. Mine Countermeasures (MCM);
3. Anti-Submarine Warfare (ASW);
4. Inspection/Identification (ID);
5. Oceanography/Hydrography;
6. Communication/Navigation Network Nodes (CN3);
7. Payload Delivery;
8. Influence Activities (IA);
9. Time Critical Strike (TCS).

Also, specific platform size is linked with specific mission within the nine areas, these will also be presented. Commercial applications of UUVs are also summarized but they mostly overlap with the areas identified above.

2.1.1 Intelligence, Surveillance and Reconnaissance

Persistent ISR is an identified need for the maritime domain. ISR is important not only for the traditional purpose of intelligence collection, but also as a precursor and enabler for other missions and applications of UUVs [6].

The purpose of performing ISR missions from an UUV is to collect intelligence data above and below the ocean surface (electromagnetic, optical, air sampling, weather, acoustic signals, water sampling, ocean bottom equipment monitoring, and object localization) while remaining undetected by the enemy [6]. Specific ISR UUV capabilities include persistent littoral ISR, harbour or port monitoring, Chemical, Biological, Nuclear, Radiological, Explosive (CBRNE) detection and localization, surveillance sensor emplacement, battle damage assessment, active target designation, and more.

The ISR mission area encompasses collection and delivery of many types of data: intelligence collection of all types (imagery, acoustic, water profiling), target detection and localization, and mapping (e.g. Intelligence Preparation of the Battlespace (IPB) and Oceanography). UUVs are uniquely suited for information collection due to their ability to operate at long standoff distances, operate in shallow water areas, operate autonomously, and provide a level of clandestine capability not available with other systems [3].

In an operational context, a UUV is launched from a platform of opportunity, submarine, surface ship, or even an aircraft or shore facility and then proceeds to the designated observation area. It then performs its mission, collecting information over a predetermined period of time. It autonomously repositions itself as necessary, both to collect additional information and to avoid threats. The information collected is either transmitted back to a relay station on demand or when self cued (i.e., when the vehicle records a threat change and determines that transmission is necessary) ([6], [5], [3]).

Possible ISR UUV missions include ([3], [5], [6]):

- Persistent and tactical intelligence collection : Persistent surveillance favours the use of large AUVs to deploy long-lived leave-behind sensor systems as platform autonomy is required. Also, in view of the extraordinary challenges entailed in performing Signal Intelligence (SIGINT), Electronic Intelligence (ELINT), Measurement and Signatures Intelligence (MASINT) and Imagery Intelligence (IMINT) missions autonomously, AUVs are not recommended for such missions [5].
- CBRNE detection and localization both above and below the ocean surface : AUVs equipped with purpose-built mass spectrometers have detected chemical plumes. The ability to recognize simple chemical compounds has been demonstrated. Beyond plume detection, AUVs offer unique potential for the detection of shipboard radiological materials that could be threatening or present proliferation challenges. It is not always possible for humans to inspect vessels for radiological materials and as signals from radiological materials decrease with range, longer dives are required. Diver endurance is an issue here, especially in harsh environments (such as cold water) [5].
- Near-Land and Harbour Monitoring : provide protection for special operation forces during infiltration and exfiltration in over-the-beach operations by : identifying areas with the lowest levels of activity, warning special operation forces operators of possible threats of detection, and by providing overwatch for caches of supplies and equipment as special operation forces operators conduct missions inland [5].
- Deployment of leave-behind surveillance sensors or sensor arrays : The deployment of leave-behind surveillance sensors or sensor arrays is viewed as a crosscutting mission that applies to leave-behind sensors for the SIGINT, ELINT, MASINT, IMINT and acoustic intelligence missions. The feasibility of using AUVs to deploy leave-behind acoustic arrays has already been demonstrated [5]. Large AUVs may also be able to deploy other leave-behind systems such as sea mines in enemy military ports in time of war.
- Specialized mapping and object detection and localization : accomplished with a mix of divers, manned vehicles, and UUVs, have been ongoing for decades. These missions have been conducted to identify weapons, wreckage, and debris.

Critical technology and engineering issues pertaining to the ISR UUV mission capability stem from the need for long transit distances, long times on station, clandestine operations, signature reduction, failsafe vehicle behaviours, vehicle stability, and extended autonomous operation [6].

Improvements in current UUV communication capabilities are also required [6].

2.1.2 Mine Countermeasures

MCM mission requirements are driven by the need to rapidly establish large, safe operating areas and transit routes and lanes [6]. Seven to ten days is emerging as the requirement to complete all MCM operations in specified areas, but clearly, quicker is better [5].

The objective of this MCM capability is to find or create areas of operation that are clear of sea mines without requiring manned platforms to enter suspected mined areas, and to shorten MCM timelines [6].

MCM is perhaps the most problematic of the missions facing the UUV. The proliferation of mine types, their availability to potential adversaries, their ease of employment over a wide spectrum of water depths, and the nature of MCM operations, where there is no tolerance for mistakes, combine to make the MCM mission one of the most challenging [6].

MCM mission types can meet these requirements against the myriad of mine threats in operational environments. These include [6]:

1. Reconnaissance - Detection, Classification, Identification and Localization;
2. Clearance - Neutralization and Breaching;
3. Sweeping - Mechanical and Influence;
4. Protection - Spoofing and Jamming.

The functions of MCM that lend themselves to near-term UUV solutions are minehunting and neutralization. These can be further broken down to the following phases: detect, classify, identify and neutralize.

MCM benefits from the ISR and oceanography missions. UUVs can gather oceanographic data long before hostile operations to provide data on winds, bathymetry, water visibility, currents, waves, bottom geophysical parameters, kelp concentrations, sand bars, etc. to determine mineable areas and previous bottom surveys can be compared to current ones to determine changes in mine-like contacts [6].

Near- to mid-term UUV technology can realistically contribute to solve the emerging MCM requirements. It also indicates that large UUVs may not be required for these missions; while they certainly could perform the missions, larger numbers of smaller vehicles may be operationally better suited, provide greater mission flexibility, and facilitate graceful system degradation [6].

Currently tested payload for MCM is a low-frequency broadband synthetic aperture sonar. In this case, the UUV is retrieved from water and data from the UUV is downloaded from a Removable Data Storage Module (RDSM) for shipboard analysis.

2.1.3 Anti-Submarine Warfare

The objective of ASW is to patrol, detect, track, and hand off adversary submarines using UUVs [3]. Traditionally the task of ASW is a person-intensive discipline with various levels of sophisticated sensors gathering large amounts of data, from towed array or sonobuoys for example, from which the relevant information, in terms of possible target or nonrisk assessment can be made [7].

Alternative approaches in ASW have recently been suggested concerning distributed mobile and stationary sensors, such as sonobuoys and AUV [7].

Three categories of ASW operations are broadly defined and can be described as [3]:

1. Hold at Risk : monitoring all the submarines that exit a port or transit a chokepoint;

2. Maritime Shield : clearing and maintaining a large maritime force's operating area free of threat submarines;
3. Protected Passage : clearing and maintaining a route for a maritime force from one operating area to another free of threat submarines.

UUVs offer significant force multiplication for ASW operations in the Hold at Risk scenario in which a UUV, aided by third-party signaling, monitors and tracks the submarine traffic through an adversary port egress or other choke point. While offering some advantages in the other two categories, the UUVs limited mobility and the lesser need for stealth make UUVs less ideal candidates in those cases [3].

In addition, given the potential restriction of access due to bathymetry or threat, the fact that undersea forces may be the only forces available early enough, and the desire to track submarines regardless of the stage of conflict, the UUV is a leading candidate for the Hold at Risk task ([6], [5], [3]).

AUVs are also seen as a possible addition to the field of ASW , with the potential of being part of a multistatic active sonar network. Their benefits also include covertness, reduced risk, reduced man power, potential persistence and the ability to optimize sensor position in 3D space based on incoming sensor data [7].

In the future, the mission of ASW could see the rise of an autonomous approach to the problem. The vision of groups of networked unmanned vehicles swimming around independently, carrying out high-level processing and sharing information between other members of the submerged fleet, ultimately carrying out detection and classification of enemy assets and passing the information to a command and control centre, or carrying out their own prosecution, is seductive and enticing [7].

2.1.4 Inspection / Identification

This mission stems from the need to efficiently inspect ship hulls and piers for foreign objects, such as an explosive device, to keep harbours and choke points safe. Currently, hull and pier inspection is generally both time and manpower intensive [3].

Preparing a ship for divers may take several hours, and it requires coordination, as some damage control systems may have to remain on-line. Searching for unexploded ordnance that is typically time-fused is particularly hazardous to divers. Use of an unmanned vehicle can reduce the risk to divers by providing precise location of suspicious objects, while relieving the divers of the tedious search process in cluttered environments ([6], [5], [3]).

2.1.5 Oceanography / Hydrography

All maritime platforms; manned and unmanned, surface, air and undersea; can gather oceanographic/hydrographic data to varying degrees in parallel with their other missions. Dedicated oceanographic/ hydrographic operations occur worldwide; these operations will be augmented by

UUVs operating from survey ships and ships of opportunity that may be used as a platform for plug and play unmanned systems [6].

Currently, UUVs are revolutionizing oceanography. They have been widely used for in-situ measurements which would be difficult, expensive, and, in some cases, impossible to obtain by using traditional ship-based sampling techniques [8].

Oceanography/hydrography missions for UUVs operations include [6]:

- Bathymetry;
- Acoustic imagery;
- Optical imagery;
- Sub-bottom profiling;
- Water column characterization;
- Ocean current profiles (with tides);
- Temperature profiles;
- Salinity profiles;
- Water clarity;
- Bioluminescence;
- CBRNE detection and tracking.

These missions support safety at sea and all naval warfare areas [6].

The objective of oceanographic missions ranges from broad reconnaissance of large littoral undersea areas to detailed characterization of specific battlespace areas collecting high quality, accurately positioned data. The focus is on the littoral, but a deep-water survey capability is required for bottom characterization to accomplish cable route pre-installation and inspection [6].

UUV technology is a force multiplier to manned platforms and is essential to meet critical oceanography requirements. The predominant driver for adopting UUV technology for ocean survey is to increase the timeliness and cost effectiveness which helps to acquire affordable, near real time data at required temporal and spatial sampling densities. Used in conjunction with remote sensors, other ocean data, and models, UUV-acquired data provides warfighters with critically required foreknowledge of environmental parameters such as bathymetry, tides, waves, currents, winds, acoustic propagation characteristics, locations of hazards to navigation, and other objects of interest [6].

The shallow-water littoral region survey is useful in aiding navigation or projecting sensor performance. This type of mission may be best accomplished using small UUVs or gliders [6]. Gliders (AUVs notable for their endurance) can gather tactically useful oceanographic data under adverse weather conditions and significantly enhance the quality and quantity of oceanographic data available to warfighters[5].

Oblong in shape, gliders use internal weight balancing and water temperature changes to move for months at a time. While design improvements are enabling greater payload volume and quicker

speed, the new capabilities of gliders will come from sensors that can be small enough and draw very little power to the on-board battery [2].

Gliders used today for oceanography cost only tens of thousands of dollars, can collect oceanographic data continuously while deployed for months at a time, and can be refueled at minimal cost. They are cheap enough to be considered expendable. Gliders being tested today are designed to last for years, during which time they could continually collect oceanographic data [5].

2.1.6 Communication/Navigation Network Nodes

The CN3 capability is a support function enabling other systems to perform their missions more effectively. Its objective is to provide a low-profile communication and navigation relay function for a wide variety of platforms. The advantages offered by using a UUV include extended standoff distances and greater accessibility. CN3 will provide submerged communications to undersea platforms in areas not otherwise available [3].

One immediate application of the CN3 would be a self-deploying transponder network. A CN3 UUV could be launched from a safe distance, transit to the operations area using Global Positioning System (GPS), and then deploy itself as a transponder node for operations [3].

UUVs can also serve as an aid to navigation acting as stand-by buoys, positioning themselves at designated locations. UUVs can also provide the link between subsurface platforms and GPS or other navigation systems, without exposing the platform to unnecessary risk.

Prepositioned beacons could be placed to provide navigational references in circumstances where conventional means are not available or desirable for use. This makes them attractive for a variety of communication and navigation functions including the following [6]:

1. Communication: underwater network nodes for data transmission;
2. Underwater connectors;
3. Low aspect deployed antennas (SATCOM, GPS);
4. Navigation: Deployment of transponders or mobile transponders;
5. Inverted GPS capability (antenna to surface);
6. On-demand channel lane markers (to support Amphibious Assault).

UUVs have a limited ability to communicate with the outside world and the use of UUV, in particular for CN3, requires considerable electrical power for transmissions [6].

2.1.7 Payload Delivery

Payload delivery is not a mission in itself, but is necessary to support a number of other mission areas by providing the energy, navigation, autonomy, and payload deployment systems [6].

Large UUVs can facilitate logistics by providing covert supply and support without exposing high-value platforms. Potential payloads include ([3], [6], [5]):

1. Sensors or vehicles deployed in support of ISR, ASW, Mine Warfare;
2. Oceanography, CN3 or TCS;
3. Weapons to deploy or preposition;
4. Supplies to preposition for Special Operations Force or EOD missions;
5. MCM neutralization devices;
6. Cargo as a follow on behind Swimmer Delivery Vehicles.

The UUVs involved will require a high degree of autonomy, good navigation capabilities, and a large energy store. Required vehicles are relatively large and require a corresponding propulsion system. UUV recovery following mission completion will be expected [5].

2.1.8 Influence Activities

Two IA roles are well suited to UUVs: first, as a platform to jam or inject false data into enemy communications or computer networks, and second, as submarine decoy [3].

The objective of IA is to deceive, deter and disrupt enemies [6]. UUV capability to operate covertly in shallow waters and areas too hazardous for a manned platform makes them ideally suited for several IA missions which could not be performed by other platforms ([3], [6], [5]). This enables the transport of a transmitter and antenna to close proximity of susceptible communications nodes.

The technology to support IA exists or can be easily leveraged from other sub-pillars. Submarine simulators have long been employed as ASW targets ([3], [6], [5]).

2.1.9 Time Critical Strike

TCS is one of the lower priority missions for UUVs. An autonomous weapon launch capability is controversial, and man-in-the-loop control of weapon launch will be required for the foreseeable future [3]. However, UUVs can provide low-risk, high payoff augmentation to strike missions, providing an ability to covertly deliver weapons to close-in launch points [3]. The TCS mission was ranked as moderately suitable for UUVs and it could be better performed by other platforms.

2.1.10 Other applications

Other application for the UUVs, not part of the U.S. UUV Master Plan ([3]) have also been identified and are reported in [5], these include :

- Undersea Test Platform : designed to be large enough that they faithfully reproduce the hydrodynamic and acoustic properties of actual submarines and can accommodate the installation of nonintrusive critical instrumentation but small enough to minimize the costs of design testing and demonstration.
- In-Stride Minefield Transits: would enable ships to safely transit suspected minefields without advanced preparation or outside assistance and without stopping or turning back in the minefield.
- Submarine Search and Rescue;
- ASW Training : UUVs are used to simulate submarines as ASW targets in open-ocean and instrumented range exercises.
- Monitoring Undersea Infrastructure, although this one is closely related to the Inspection/I-identification mission

More commercial missions and applications could also be considered for UUVs such as Oil and Gas exploration, undersea cable inspection, nuclear-industry inspection, commercial salvage and aquaculture [5] .

2.1.11 Summary

The UUV Master plan [3] provides a ranking in mission priorities (extracted from [9]) and their suitability for UUVs as well as specific mission with respect to UUV's size. Table 2.1 tries to summarize these concepts.

2.2 UUV applications in the canadian context

The Canadian Navy's development and deployment of autonomous marine systems is currently limited to only two mission areas : MCM and oceanography [4]. Also, as stated in [10], there are several operations that will be critical to the future CF Navy and all benefit from UUVs: Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR), ASW and MCM. However using unmanned vehicles in mission areas like payload delivery, ASW and ISR is not part of the navy's current considerations [4].

Increased interest in the Arctic - as a shortened shipping route between Asia and Europe and as a source of vast resources increasingly open to exploitation as the climate changes - means that there will be a growing need to know what is under the surface of Arctic waters [11].

The need for full time and reliable awareness of the Arctic maritime domain is not a matter of debate. It is part of the exercise of sovereignty and is central to meeting security and public safety objectives. It is obviously important for a host of environmental, commercial, and economic reasons as well [12].

Unmanned underwater vehicles may be able to augment current naval platforms and capabilities in this mission area with minimal costs [4]. The increasing sophistication of signature reduction

Table 2.1: Missions (in priority order) and suitability for UUVs

Mission	Suitability for UUV	Man Portable	Light Weight	Heavy Weight	Large
Intelligence, Surveillance, and Reconnaissance (ISR)	High	Special Purpose	Harbor	Tactical	Persistent
Mine Countermeasures (MCM)	High	<ul style="list-style-type: none"> • Very Shallow Water • SCM • Neutralizer 	Area Clearing	Clandestine Recon.	
Anti-Submarine Warfare (ASW)	High				Hold-At-Risk
Inspection / Identification	High	<ul style="list-style-type: none"> • Homeland De-fense • Anti-terrorism • Force Protection 			
Oceanography	High		Special Purpose	Littoral Access	Long Range
Communications / Navigation Network Node (CN3)	Medium/High	Very Shallow Water	Mobile CN3		
Payload Delivery	Medium				MCM, ASW, TCS
Information Operations (IO)	Medium		Network Attack	Submarine decoy	
Time Critical Strike (TCS)	Medium				See payload delivery

Table 2.2: Applications and cost saving

Application	Cost saving
CBRNE Detection (ISR)	93%
Water Column Profiling (Oceanography)	99%
Mapping (Oceanography)	<ul style="list-style-type: none"> • High Definition : 76% • Medium Definition : 93% • low Definition : 93%
Harbor Monitoring (ISR)	98%
Array deployment (ISR, Payload delivery)	88%
Mine-hunting (MCM)	92%
Hold-at-risk (ASW)	96%
ASW Training (ASW)	81%
Hull inspection (Inspection / Identification)	60%
Undersea Infrastructure (Inspection / Identification)	86%

technology and the more difficult littoral-operating environment will increase the challenges of detecting and identifying Targets Of Interest [10]. Canada’s vast coastlines could be surveilled continuously and with limited costs by autonomous systems [4].

Referring to the Hold at Risk scenario of ASW, UUVs can provide major force multiplication for existing ASW forces [6]. This concept of operation can be used effectively in specific choke points in the North West passage to contribute to the ISR mission in addition to the ASW one.

Understanding and appreciating the environment through data collection, that includes bathymetry and hydrography, is also necessary [13]. Oceanographic mission is a must, especially in Arctic, to provide the military, industry and academia with quality data in order to give them a competitive advantage on the strategic, commercial and research level. Gathering data about the seafloor and oceans water will serve to support them in various domains.

Finally, the cost saving benefits of using unmanned systems in maritime environment should not be overlooked. Detailed UUV Mission Cost Analysis and Comparison was conducted in [14]. The results of cost reduction for some UUV are presented in table 2.2.

One should refer to [14] for detailed description of cost calculation comparison for manned Concept

of Operations (CONOPS) versus UUVs CONOPS for the cost reduction presented above.

To summarize, specific ISR UUV capabilities in a Canadian context would include persistent littoral ISR including ASW in specific choke points, CBRNE detection and localization, surveillance sensor emplacement in addition to the current MCM and oceanography missions. These areas of application are of tremendous interest for Canada, especially in remote locations, such as the Arctic region, from strategic, economic and environmental points of view.

Part 3

UUV Sensor payload

Sensor payload can be categorized into six groups: acoustic sensors; magnetic sensors; electromagnetic sensors; optical sensors; CBRNE sensors; and Conductivity - Temperature - Depth (CTD) sensors [5]. This section focuses on describing the sensors that appear reasonable from a Canadian perspective, namely :

- Acoustic sensors, which support a wide range of AUV's missions [15];
- CTD sensors as quality environmental and ocean data collection is integral to many mission's goals [16];
- And CBRNE detection sensors as CBRNE detection and localization (both above and below the ocean surface) is part of ISR mission [5] as is likely to grow in importance in the future.

3.1 Acoustic sensors

Acoustic signals propagate better than light and radio waves or any other types of energy in underwater applications. The importance of acoustics for underwater applications is undeniable, and the enabler device is an acoustic sensor. Acoustics are utilized to fulfil the needs of sonar and underwater communications in scientific explorations, commercial exploitations, defence surveillance and environmental protection for many decades [15]. They are commonly used to support a broad range of AUV's missions such as :

- ASW for detection and tracking of submarines;
- Oceanography by providing bathymetric data for underwater mapping;
- ISR by, for instance, enabling AUVs to participate in acoustic intelligence missions [5].

Sonar (originally an acronym for SOund Navigation And Ranging) is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, communicate with or

detect objects on or under the surface of the water, such as other vessels [17]. UUV sonars, which used to be relatively simple systems, are now capable of sophisticated processing.

Two types of technology share the name sonar: passive sonar is essentially listening for the sound made by vessels; active sonar is emitting pulses of sounds and listening for echoes. Sonar may be used as a means of acoustic location and of measurement of the echo characteristics of "targets" in the water.

UUVs use active sonars (i.e., sonars that transmit and receive sound pulses) to map out their environments and detect objects of interest. Passive sonars are used primarily for ASW missions.

Obstacle-avoidance sonars have evolved from simple, forwardlooking active sonars into multibeam sonars that use advanced signal processing techniques to obtain maximum information for obstacle avoidance.

Acoustic imagery is commonplace today and sensor types include Side Looking Sonar (SLS) (backscatter information), multi-beam sonar (high-resolution ping-by-ping digital terrain models), and imaging sonars that function similarly to SLS systems. Native data formats are largely determined by the manufacturer, but most are easily converted to U.S. Navy-standard formats, such as Unified Sonar Image Processing System (UNISIPS) [16].

Until recently, ship sonars were usually with hull mounted arrays, either amidships or at the bow. It was soon found after their initial use that a means of reducing flow noise was required. Because of the problems of ship noise, towed sonars are also used. These also have the advantage of being able to be placed deeper in the water. However, there are limitations on their use in shallow water. These are called towed arrays (linear) or variable depth sonars (VDS) with 2/3D arrays. A problem is that the winches required to deploy/recover these are large and expensive. VDS sets are primarily active in operation while towed arrays are passive.

For the AUV perspective, it is usually a towed array because of the small size of the AUV.

To summarize, acoustic data from a UUV can provide :

- Object detection (mine, submarine, etc. . .) using active/passive sonar measurement;
- Imaging multi-frequency sonar are used for : offshore oil and gas, sunken timber recovery, diving support, surveying, search and recovery, inspection, underwater archeology and many scientific research.
- bathymetric data for underwater mapping;
- A mean of communication through acoustic modems.

3.2 Conductivity - Temperature - Depth sensors

Oceanographers need to know the distribution of temperature and salinity for many reasons. When surface waters sink into the deep ocean, they retain a distinctive relationship between temperature and salinity which can act as a tracer to help track the source of ocean waters. Temperature and

salinity are also needed to compute the density of seawater. Since density is also related to the horizontal pressure gradients and ocean currents, knowledge of temperature and salinity provides a powerful tool for understanding the world's oceans [18].

These sensors provide data in support of other sensors used for oceanography, hydrography, ASW, home land security, MIW, Naval Special Warfare, and many other mission related tasks.

CTD sensors, which are generally deployed together as packaged systems, are used to collect oceanographic data and predict and improve the performance of onboard sonars. The conductivity of seawater is closely linked to its salinity. Salinity, temperature, and depth are, in turn, the predominant factors used to predict undersea sound velocity. Therefore, CTD sensors can be thought of as calibrating tools for the active sonars described earlier [5].

3.2.1 Standard file formats for CTD data

In oceanography, temperature measurements from CTD sensors can be used to detect water temperature anomalies that may indicate the presence of volcanoes or hydrothermal vents. CTD sensors outputs are also used to compute sound velocity profiles which are used to calibrate the output of other sensors, most importantly acoustic devices.

Temperature and salinity measurements are often point measurements at UUV depth. If possible, averaging of data should be avoided. Plain text metadata for the measurement normally consists of the value of the measurement; the resolution or precision of the measurement; and the latitude, longitude, depth, and time of the measurement. If averaging or sub-sampling of the data was performed, the method should be fully described in the metadata [16].

Table 3.1 is an example of CTD data and is usually provided in CSV/ASCII format ([19])

The derived information i.e. the sound velocity profile, is usually an ASCII file of two columns of depth versus sound speed (.asvp file type).

3.3 Chemical - Biological - Radiological - Nuclear - Explosive detection sensors

CBRNE detectors are used to detect the presence of a hazardous substance in the marine environment. Hazardous substances and organisms in marine waters may derive from anthropogenic or natural sources [20]. Pollution of national waters remains a constant threat and the growth of maritime traffic around the globe, and in particular in the North West passage, demands increase surveillance to detect as soon as possible pollutants to reduce their impacts. In addition, despite the existence of a broadly accepted regime of international agreements addressing the obligations of states parties in respect of matters such as the development, stockpiling, proliferation and use of certain CBRN weapons, potential adversaries continue to develop and field CBRN weapons or substances [21].

CBRNE detectors carry an importance both for national security and environmental protection.

Table 3.1: CTD output example

Lat(DecDeg)	Long(DecDeg)	sec since start	Depth(m)	Temp(oC)	Cond(S/m)	Sal(PSU)	OBS	ORP	Depth(m)
42.7546667	-126.7080333	0	14.124	13.0073	3.840804	32.563	0.1827	164.52	14.124
42.7546667	-126.7080333	5	13.984	13.0299	3.842843	32.5629	0.1419	164.96	13.984
42.7546667	-126.7080333	10	14.01	12.9669	3.837115	32.5629	0.1441	165.34	14.01
42.7546667	-126.7080333	15	13.984	12.8824	3.829198	32.5607	0.1814	165.68	13.984
42.7546667	-126.7080333	20	14.652	12.7109	3.814148	32.5655	0.1849	166.18	14.652
42.7546667	-126.7080333	25	15.639	12.4453	3.790521	32.5695	0.1827	166.52	15.639

From a practical point of view, underwater CBRNE detection can be divided in three broad categories since these require different types of sensor payload to achieve their detection :

- Chemical and biological hazards detection;
- Radiological and nuclear detection;
- Explosive detection;

Chemical and biological substances to be detected include a huge variety of different compounds, such as petroleum hydrocarbons, marine toxins and metal pollutants. Spectroscopic methods are the common approach for such chemical detection.

Petroleum hydrocarbons can be observed in situ with multispectral sensors or by detection at selected wavelengths of different optical properties of oil, among them fluorescence, reflection and absorption. Surface-enhanced Raman scattering is a spectroscopic method for the detection of petroleum hydrocarbons suitable for in situ measurements. The high specificity and fingerprinting characteristics of Raman spectra allow for substance identification in mixtures [20].

In the investigation of chemical pollutions, such as petroleum hydrocarbons at low (ppm) or trace concentrations (ppb) in sea-water, surface-enhanced Raman scattering (SERS) effect reveals an immense potential regarding the marine environment [22]. A laser Raman spectrometer was deployed on ROVs with successful operation at 3600m depth [22].

Some commercially available detectors for various parameters also show promise for field deployment for detecting metal pollutants [20].

With regards to marine toxins detection, which are non-volatile compounds, they are not readily amenable to certain chemical analytical techniques, such as gas chromatography coupled with mass spectrometry (GC-MS), and appropriate derivatization methods for detection are not commonly available. Current applications of liquid chromatography with mass spectrometry to marine biotoxin analysis are limited to laboratory extracted and serially injected discrete samples [20].

Chemical plume detection have already been tested. However, one of the issues for plume chemical detection and mapping with AUV would be detection in a turbulent flow environment where the AUV sampling is too coarse relative to the spatial and temporal rates of change that can occur in the environment [23].

Nuclear and radiological detection is not yet operational but is the ultimate dirty mission of UUV. It is normally conducted by using Gamma Spectroscopy. Some sensors are being developed to detect radiation in marine environments. A gamma-radiation probe has been developed for radionuclide detection within a stationary monitoring network for radioactive contamination in the marine environment (by German BSH, Federal Maritime and Hydrographic Agency) and similar systems have also been developed by the Hellenic Center for Marine Research in Greece for the measurement of marine radiation, where the output is configured to be transmitted via satellite to the base station [20].

On the explosive detection side, quantitating explosive materials at trace concentrations in real-time on-site within the marine environment may prove critical to protecting civilians, waterways,

and military personnel. However, there is not much literature available on that particular topic.

The U.S. Naval Research Laboratory developed an immunosensor capable of detecting trace levels of explosives that has been integrated into REMUS payload for use in the marine environment [24].

Since most of the sensors used for CBRNE detection revolve around spectroscopy, one can assume that the standard output is a spectral file which enables the identification of the chemical element presents. This kind of file is usually an ASCII file.

The technology of detecting chemical plumes is advancing, and UUVs could offer a solution to problems of shipboard radiological detection [5]. Taking into account the future sensor development around spectroscopy, the CBRNE detection mission is a very promising mission for AUV.

A compilation of commercially available in situ sensors for long-term applications in marine environments can be found in [20].

Combined with other sensor payloads, such as GPS and CTD sensors, the CBRNE detection sensors can provide an analyst with a clear picture of what material is present in the water as well as its position. Knowing the water dynamics may enable one to predict the behaviour of a detected chemical plume.

An integrated system within an AUV offers several key benefits relative to other solutions [25]:

- Cost-feasible for commercial applications : AUV integration delivers more cost-effective mapping of light hydrocarbons over large areas, which is critical as mass spectrometry expands from a research instrument to a valuable data-gathering tool for commercial applications in the oil and gas industry.
- Ability for continuous measurement : The true value of underwater mass spectrometers is the ability to achieve continuous measurement of volatile gases, light hydrocarbons, and organic compounds. By untethering underwater monitoring equipment from the ship, surveys can traverse large areas of the ocean or extended pipelines without interruption, enabling individual and multiple survey collections of real-time data each time the AUV is submerged.
- Reduced operational risk : Underwater hydrocarbon survey launch and recovery operations involving equipment tethered to ships pose a greater risk the longer the connection is in place. Shifting to an AUV-based survey reduces operational risks to personnel and vital and costly equipment.
- Increased quality of data : The stability of AUVs leads to an increased quality data collection process. Untethered from a surface vessel, maneuverability is more precise and navigation more accurate. AUVs collect high quality geo-referenced data more efficiently than towed systems.

3.4 Summary

This section described sensor payloads necessary to successfully perform missions in the Canadian context. Acoustic and CTD sensors are already widely used and the CBRNE detection sensors are getting more and more attention. Development and integration of these new sensors into UUV payload will become reality in a near future.

With these sensors, UUV are able to support the following missions : Persistent ISR, ASW, MCM as well as oceanographic missions. These are likely to give Canada a competitive advantage on the military, industrial and academic areas given that the produced data and information can be effectively understood and share across multiple agencies and organizations.

The next chapter presents an overview of the different data formats and information exchange standards related to the UUV-collected data and information.

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Part 4

Interoperability requirements and Standards

Data standards are the common vocabulary used to describe the shared data objects and the models themselves [26].

Standards can be seen from two different angles. Data encoding standards and information exchange data model standards. The first one is linked to the data and information produced by the sensor. As standards are needed for sensor data outputs, data exchange standards are also needed for data discovery and sharing to insure interoperability between government agencies and coalition partners [26].

This section deals with both and is organized as followed :

- First, the problem of data and information sharing is discussed in section 4.1;
- Then, an overview of the standards associated with the data types produced by the sensors described in section 3 is presented in section 4.2;
- Finally, an overview of the information exchange data model standards currently used to describe, discover and share data and information between national agencies and or international partners is provided in section 4.3.

4.1 Interoperability requirements for Maritime Domain Awareness

It has been recognized that situational awareness products are required to respond to emergency situations and management of crisis ([27], [28]). Such situation awareness products are developed through collaborative information environments which help decision makers of various organizations (government, civil or military) effectively share/exchange information about on-going events [28] while protecting sensitive/classified information [27].

AUV can contribute to the enhancement of situation awareness in the maritime area, which is usually called MDA. MDA is a multi-layered, multi-domain picture that links the identity, location, known patterns and present activity of ships, cargo, people, and hazards within and adjacent to the maritime domain [29].

MDA derives from the pooling of a comprehensive set of mostly unclassified data contributed by the many agencies and nations with knowledge of the maritime domain [29]. It is a compilation of information ranging from environmental data (oceanographic, meteorological, etc.) to vessel positions and characteristics, to cargo manifests and supply-chain information, to biometric identification data, to regional activity patterns (fishing areas, commercial routes, seasonal variations, etc.) [29].

A sub-domain of the MDA is the Underwater Domain Awareness (UDA), which is an aggregation of maritime undersea monitoring strategies, processes and data relating to the following [11]:

- monitoring and assessments of the density of biological entities such as fish, whales, plankton or other species;
- geophysical activity of the earth's crust for tsunami warning;
- maritime industrial exploration and exploitation efforts; and,
- security/defence monitoring and assessment to track the threat posed by submarines, mines and the employment of undersea systems by transnational agents - for example criminal gangs - seeking to avoid detection.

While not all-inclusive, this list of information illustrates the depth and complexity of maritime information contributing to MDA and that it far exceeds what can be gathered by one organization sensors, data or information alone [29]. Multinational collaboration is also mandatory if adequate MDA is to be achieved [30].

As stated in [12], the international security dimension of domain awareness is critical, not because of dire or imminent national security threats to the region, but because of the value of ongoing confirmation of the absence of such threats. One of the primary obligations of neighbouring states toward one another is to provide credible assurances that they each prohibit and prevent events or activities within their respective jurisdictions that would pose a security threat to their neighbours or the neighbourhood generally. For those to be credible assurances, each state obviously needs to know what is happening within its own borders and in particular it needs to be prepared to share such knowledge with appropriate authorities across borders within the region [12].

A review of the literature generated by the United States armed forces and other allies makes it clear that the acquisition, integration, and analysis of information and intelligence to generate a comprehensive Common Operating Picture (COP) and distribute it to all levels of command for decision-making is vital [10]. And in order to achieve the required collaboration level in crises, cross domain information exchange is crucial so that all actors have the same situation awareness [28].

However, in the past, information management within organizations has lead to a situation where most of their systems have become stove pipes, working independently from each other [31]. In

addition, they mostly use proprietary data model standards. As such, information sharing is possible only with delay or not at all and it prevents provision of full situation awareness to decision makers [32]. Also, given the vast amounts of information currently available in multiple locations, it is often difficult to find the specific information that is needed in a timely fashion [33].

To overcome these problems, systems have to become interoperable in order to be able to share information in a timely manner [32].

The main barrier to achieve technical interoperability is the divergence of data/object model interoperability layer standards and specifications used in military and civil domains [28].

The goal of standardizing cross-boundary information exchange is to promote and enhance agency capabilities for the development of shared services and increasing the sharing of information. Standardizing information exchange includes the business processes, policies, procedures, architecture, and governance that support effective decision-making and mission-focused actions by providing timely, accurate, and relevant information to the appropriate individuals across all levels of government [34].

As stated in [10], a significant national application of information exchange for Canada, would be to upgrade the Recognized Maritime Picture (RMP) that the navy presently produces and makes available to various other government departments with additional inputs from a variety of air, sea and space-based assets.

4.2 Data formats standards

North Atlantic Treaty Organization (NATO) along with other committees and organizations are working on standardization processes for Maritime Unmanned System (MUS). In particular in the UUV domain, Science Applied International Corp. / Association for Unmanned Vehicle Systems as well as the American Society for Testing and Materials (ASTM), and Battle Applied Coastal and Environmental Services, have produced a paper outlining the best employment for UUV [6].

The initial UUV standards related to data formats and data storage Media, developed by ATSM in close collaboration with governmental, military, academia with an interest in UUV development and interoperability, are presented in [16]. Some of these standards, which are related to the sensors of interest in this report are presented below.

However, military applications of UUVs often mandate unusual and even non-standard data collections and formats. As a result, conforming to national and international standards may not always be possible. However, as stated in [16], to the maximum extent practicable, UUV data collection formats and standards should follow World Meteorological Organization (WMO), Intergovernmental Oceanographic Commission (IOC), and similar national and international standards.

It is worth mentioning that the standards below are already supported by a wide range of data processing software. The knowledge of the details is unnecessary to work with those. Therefore, for most of the data standards presented below, their learning curve is closely linked to the learning curve required to use the processing software.

4.2.1 NATO Standards

According to NATO, since Unmanned Aerial System (UAS)s are at the forefront of technological development. MUS should follow the trend and base their technical architecture, digital backbone, communications and robotic interfaces on established parameters [6].

Several standards have been adopted within NATO for UAS data storage purpose. Adopting the standards outlined in the following STANAGs is integral to the interoperability of NATO UAS and their payloads [6]:

1. 3809 Digital Terrain Elevation Data Geographic Information Exchange Standard.
2. 4575 NATO Advanced Data Storage Interface (if advanced storage is required).
3. 4545 NATO Secondary Imagery Format.
4. 4559 NATO Standard Image Library Interface (if interface with image library is desired).
5. 4607 NATO GMTI Data Format (Emerging Standard).
6. 4609 NATO Digital Motion Imagery Format (Emerging Standard).
7. 5500 NATO Message Test Formatting System AdatP-3.
8. 7023 Air Reconnaissance Imagery Data architecture.
9. 7024 Imagery Air Reconnaissance (Digital Tape Storage) (if tape storage is required).
10. 7085 Interoperable Data Links for Imaging Systems + Digital Point to Point Annex of STANAG 7085 (compatible with CDL/TCDL specification).
11. 7074 Digital Geographic Information Exchange Standard (Version 2.1).

Some of these standards are applicable for the sensor payloads of an AUV, particularly those related to still and motion imagery as well as geo-based data. Since the vast majority of systems within NATO countries already support these formats, AUV generated data should be compatible. For a complete description of these NATO's standards, the reader should refer to the appropriate STANAG.

4.2.2 Sensor Model Language

The primary focus of the Sensor Model Language (SensorML) is to provide a mean of defining processes and processing components associated with the measurement and post-measurement transformation of observations [35]. Namely, the purposes of SensorML are to [36]:

1. Provide descriptions of sensors and sensor systems for inventory management;
2. Provide sensor and process information in support of resource and observation discovery;
3. Support the processing and analysis of the sensor observations;
4. Support the geolocation of observed values (measured data);
5. Provide performance characteristics (e.g., accuracy, threshold, etc.);

6. Provide an explicit description of the process by which an observation was obtained;
7. Provide an executable process chain for deriving new data products on demand;
8. Archive fundamental properties and assumptions regarding sensor systems.

The main objective is to enable interoperability, first at the syntactic level and later at the semantic level (by using ontologies and semantic mediation), so that sensors and processes can be better understood by machines, utilized automatically in complex workflows, and easily shared between intelligent sensor web nodes [35].

In SensorML, the data components that result from measurements or processing from a sensor, sensor system, simulation, or process chain are specified as part of the outputs property. Thus, a sensor system might describe that it outputs time, latitude, longitude, altitude, temperature, and pressure, and perhaps state the appropriate units of measure [36].

In SensorML, each detector is modelled as a process with the following fields :

1. Metadata and reference frame;
2. Input and output;
3. Response parameters, which include calibration, error, latency, sampling period;
4. Method and algorithm to transform the input into the output.

while a system, which is a group of detectors is described with the following :

1. description : high level description;
2. identification : i.e the name, the manufacturer and the model number of the system;
3. classification : for example, the intended application of the system as well as sensor types included in this system;
4. validTime : period of validity;
5. contact :contact organization for this system;
6. documentation : for example, the user manual with its online location;
7. referenceFrame : textual description of how the reference frame is attached to the hardware;
8. inputs : independent virtual input for each measured phenomenon;
9. outputs : all measured values and a time tag;
10. processes : list of all detectors constituting the system;
11. connections : all internal connections in the system;
12. positions : specifies the position (location and orientation) of each detector and the system itself;
13. interfaces : defines a serial interface for communicating with the system (get measurements).

SensorML is especially well suited for low volume data, which can be described as observations that do not occur at a rapid rate. The desired low volume format is Extensible Markup Language (XML). Specifically, adherence to the SensorML as an XML vocabulary for self-describing dynamic sensor data is recommended for the below parameters [16]:

1. Temperature and Salinity Data;
2. Ocean Currents Data;
3. Ocean Optics/Bioluminescence Data;
4. Sound velocity Profile.

A complete and detailed description of SensorML can be found in [36].

4.2.3 Bathymetric data standard

Several data formats standards exists for bathymetric data for military and civilian application. As bathymetry is closely related to the oceanographic application of the UUVs, the most relevant standards are reported below.

4.2.4 Generic Sensor Format

Generic Sensor Format (GSF) is designed to efficiently store and exchange information produced by geophysical measurement systems before it has been processed into either vector or raster form[37].

GSF has become a standard file format for bathymetry data and is widely used in the maritime community. This single-file format is one of the U.S. Department of Defense Bathymetric Library (DoDBL) processing formats [37].

It should be noted that the National Geospatial-Intelligence Agency (NGA) maintains the DoDBL and is expected to move toward open, international standards in the future. Formats similar to GSF are under development for the interchange of vector data, such as hydrographic soundings and features and raster data, such as grid bathymetry and processed acoustic imagery [16].

The file format specifications and C source code for a library to read and write GSF files are available from [37].

4.2.4.1 Bathymetric Attributed Grid

Relying on a database to hold all the original data, processed into the form of grids of the best available representation of the true nature of the seafloor, the Navigation Surface concept extracts whatever data is required for a particular product and, through automatic manipulation and/or cartography, constructs a product suitable for a particular purpose.

In order to make this database possible, there is a need for a uniform file format that allows data to be passed between software packages, and between agencies involved in the collection, processing and dissemination of the data, while maintaining the integrity of the data and metadata at all times.

A unit of bathymetry is termed a Bathymetric Attributed Grid (BAG). A single BAG object represents one contiguous area of the skin of the Earth at a single resolution, but can represent data at any stage of the process from raw grid to final product. The name Navigation Surface (NS) is reserved for a final product BAG destined specifically for safety-of-navigation purposes. The status of any particular BAG is distinguished solely by the certification section of metadata embedded in the file.

With the evolution of digital data, also comes the necessity to accurately track and attribute this data. BAG is no exception. One of the primary goals behind the BAG initiative was to provide a way to uniformly encode, decode and exchange the information about who, what, when, where, and how the BAG file was created [38]. As such, the metadata associated with a BAG are :

1. Point of Contact;
2. Spatial Representation Information;
3. Legal Constraints;
4. Security Constraints;
5. Data Quality Information;
6. Identification Information (Data Identification, Geographic Extent);
7. Horizontal and Vertical Reference System Information (CRS).

This format has now been adopted by two commercial software suites used for bathymetric data processing and analysis, and is now being used by the U.S. Naval Oceanographic Office (NAVOCEANO) to store output from new multibeam data sets processed by the Combined Uncertainty and Bathymetric Estimator algorithm for providing robust estimates of bathymetry and uncertainty [39]. Complete specifications can be found in [38].

4.2.5 Pure File Magic

Pure File Magic (PFM) is designed to efficiently store bathymetric data and generate various representations of the data ("surfaces") for editing, display, and analysis [40].

PFM is a file format for bathymetric data that is becoming more widely used in the maritime community [40].

PFM was jointly developed by the NAVOCEANO and private partners. It allows for an unlimited amount of data to be stored in a spatially referenced, fast access data structure [41].

PFM is presently configuration-managed by the NAVOCEANO. PFM is designed to efficiently store processed soundings (after all corrections have been made for tides, draft, vessel offsets, etc.) and allow rapid editing of data outliers [40].

The various "surfaces" (binned data) created from the soundings are used both as a quality assurance tool to find outliers as well as to display the data for analysis. Final PFM surfaces may then be exported in various formats for use by other software packages (to BAG for example). The structure is particularly useful for data sets created by systems such as multibeam echosounders that collect a large quantity of data.

The goals of PFM are [40]:

1. Portability among all major computing platforms.
2. Efficiency in terms of storage volume and data access.
3. Allow rapid identification and editing of data outliers (by user-developed software).

4.2.6 Unified Sonar Image Processing System

The NAVOCEANO collects and processes acoustic ocean bottom imagery from multiple sensors at varying resolutions. The UNISIPS is a NAVOCEANO collection of programs that support post-acquisition processing of this data [16].

UNISIPS was designed to standardize the processing of acoustic imagery data. It can perform signal and image processing of raw data to create digital mosaics. UNISIPS can also use acoustic data to determine seafloor characteristics (e.g., clutter density and roughness), which are then entered into the bottom characteristics database. It provides extended capabilities, such as comparison of collected imagery to historical imagery to locate mine-like contacts [42].

4.2.7 Control and Communication Standards

Other standards exist for control and communication to and from the AUV. Overview of such formats is presented below as communication with AUV can be achieved with acoustic devices. Such control languages are used for communications between AUVs.

4.2.7.1 Compact Control Language

Compact Control Language (CCL) was originally designed specifically for use with the REMUS vehicle which has a graphical user interface that includes a plot of the vehicle's mission, position, course, attitude, depth, battery voltage and other important information. This interface was designed for use in mission planning and for play-back after the mission [43].

CCL data messages fall into a number of different categories [43]:

1. Vehicle information such as position, heading, speed, and subsystem fault status
2. Standard data such as CTD and bathymetry,
3. Special messages such as those generated when a computer-aided detection system finds an object of interest in a side-scan sonar record.

4. File transfer with acknowledgement. The format of the message is such that it can be interleaved with other types of messages (and with multiple vehicles).

A complete description of the CCL can be found in [43].

4.2.7.2 Dynamic Compact Control Language

The Dynamic Compact Control Language (DCCL) uses XML to provide a structure for defining very short messages comprised of bounded basic variable types, suitable for transmission over a low throughput acoustic channel [44].

DCCL is intended to build on the ideas developed in CCL but with several notable improvements. DCCL provides the ability for messages to adapt quickly to changing needs of the researchers without changing software code (i.e. dynamic). CCL messages are hard coded in software while DCCL messages are configured using XML [44]. Also, significantly smaller messages are created with DCCL than with CCL since the former uses unaligned fields, while the latter, with the exception of a few custom fields (e.g. latitude and longitude), requires that message fields fit into an even number of bytes. Thus, if a value needs eleven bits to be encoded, CCL uses two bytes (sixteen bits), whereas DCCL uses the exact number of bits (eleven in this case). DCCL also offers several features that CCL does not, including encryption, delta-differencing, and data parsing abilities [44].

4.3 Information Exchange Standards for System Interoperability

In addition to data standards, information standards are required to achieve system interoperability. Beyond being able to process UUV data, it is essential to be able to share and integrate the information across multiple organization each of them using different information systems. This is called system interoperability and it implies the automated exchange and interpretation of structured digital information among many heterogeneous systems. An essential prerequisite for this is the standardization of shared information [31].

Effective information exchange can enable agencies to [34]:

1. Breakdown stovepipe information systems for enhanced visibility and understanding, enabling agencies to connect the dots in their mission-centric areas;
2. Increase engagement with organizations at the federal, state, local, and tribal levels including the private sector as well as international partners;
3. Eliminate inter-agency mistrust by improved transparency, data quality, and accountability through establishing authoritative sources for information;
4. Adopt consistent policies, processes, and governance capabilities;
5. Increase use of description and definition of data and information for increased data protection and security; and

6. Realize cost avoidance through the use of repeatable processes and reusable artifacts.

Information sharing is about more than gaining access to large amounts of unprocessed or raw data. It's about defining and sharing the products of data processing, analysis or fusion. Information sharing must move beyond sharing individual data elements and include the idea of data products that are the result of analytical processes or data processing capabilities and provide operational relevance. While a contact from a radar or acoustical sensor may be of value, that same contact correlated or fused to other data providing vessel name and characteristics is more valuable to the community [26].

Significant research has been realized towards achieving interoperability at the technical level for emergency management applications; however, most of them focus on a single domain (i.e. either military or civil domain) or they do not use the prominent standards effectively [28]. Also, information sharing efforts continue to be impeded by technical, legal, and policy concerns [26]. Each data provider has legal, contractual or policy reasons that may prevent some of the data they maintain or process from being shared. However, the products of their analytical and management process may have broader releasability, which may result in multiple versions with different security controls [26].

Information exchange standards are mostly specified by means of data models. In case a data model is primarily meant for interoperability purposes, it is called an Information Exchange Data Model (IEDM) [31]. IEDM standardizes the data which is shared and exchanged between heterogeneous systems. Such a common exchange language is the obvious way to achieve interoperability at the information level [31].

Using an IEDM increases the commonalities among models, which has a number of benefits [26]:

1. Simplifies development and allows users to develop reusable processes that work across multiple record types.
2. Reduces complexity by reducing the number of overall elements that need to be supported.
3. Decreases the time and cost of maintaining the model because it is simpler and has less overlap.

However, as noted in [31], IEDMs tend to become very complex which in return results in the models:

1. being very hard to comprehend by non-modellers;
2. being difficult implementations of database and applications;
3. producing complicated data sets which are difficult to manage and process;
4. being only being used partly in practice.

Some other common problems in IEDMs are the use of unpractical modelling constructs, the weak relation with unstructured information, the difficulty to maintain and extend the model and to compare (and translate) with other models [31].

This section presents efforts made by some national or international organization to develop standards for information exchanges.

- First, the National Information Exchange Model (NIEM), developed and now widely adopted in the U.S., is presented in section 4.3.1;
- Then, an overview of the NATO Standard ISR Library Interface is given in section 4.3.2;
- Finally, an initiative of the Multilateral Interoperability Program, the Joint C3 Information Exchange Data Model, is presented in section 4.3.3.

Each of these might be of interest for UUV information sharing and its integration in the MDA. Interoperable MDA information would permit the development of a comprehensive picture to enable the understanding of everything that is occurring in the ocean from the surface through the seabed at all times [11].

4.3.1 National Information Exchange Model

NIEM is a community-driven, standards-based approach to exchanging information. Diverse communities can collectively leverage NIEM to increase efficiencies and improve decision making [45].

NIEM standards enable different information systems to share and exchange information, irrespective of the particular technologies in use in those information systems. The NIEM aims toward more efficient and expansive information sharing between agencies and jurisdictions; more cost-effective development and deployment of information systems; improved operations; better quality decision making as a result of more timely, accurate, and complete standardize information; and, as a consequence, enhanced public safety and homeland security. Moreover, creating and adopting NIEM standards means that multiple organizations can reap significant cost benefits through adoption and reuse, rather than building proprietary, single-use software from scratch [46].

The NIEM framework has several components:

1. NIEM Core: A common XML-based data model that provides data components for describing universal objects such as people, locations, activities, and organizations.
2. Domains: More specialized XML data models for individual use cases. There is a specialized domain for Maritime, along with a number of others (e.g. Justice and Immigration).
3. Information Exchange Package: A methodology for using and extending the building blocks that comes from the common and domain-specific models, and turning them into a complete information exchange.
4. Tools: Help develop, validate, document, and share the information exchange packages.
5. Governance Organization: Provides training and support and oversees NIEM's evolution over time.

The NIEM design was intended for high-level exchange rather than for machine-to-machine sharing, like a SIGINT messaging system. The typical transaction rate for such SIGINT systems would

run to thousands of messages per second. However, there are current plans to design code that allows NIEM message exchanges across networks but still between computing servers [47].

In addition to adding new NIEM types and properties to NIEM, it is possible to adapt existing external (non-NIEM) namespaces for use in the NIEM framework. This allows the use of external standards within NIEM IEPDs, without requiring that the external standards themselves be NIEM-conformant. The intent here is to allow use of external standard components exactly as they were defined [48].

NIEM is a well documented and supported standard. The NIEM program includes tools and support functions to help agencies at all levels of government take full advantage of this powerful data model [46]. Resources to support NIEM includes the following :

1. Webinars for training [49];
2. Tools Catalog to support NIEM Information Exchange Package Documentation (IEPD)s Development, Model Management / Search / Discovery [50];
3. Online training modules [51].

NIEM is not perfect. As noted in [52], the naming and design rules for NIEM are lengthy and difficult to comprehend, but simple cookbook implementations are possible without fully understanding those rules.

The flexibility and the fact the NIEM is unclassified and well documented make it a candidate of choice to share UUV information across multiple national agencies. It is worth to note that the U.S. DoD have started the implementation of a Military Operation Domain to support Command and Control data sharing requirements and the U.S. Government is adopting a NIEM first position, meaning that any new program must adhere to the NIEM standard unless it provides justification of why the use of NIEM is not feasible [53].

4.3.1.1 Maritime Enterprise Information Exchange Model

The Maritime domain of NIEM supports efforts for full MDA: the effective understanding of anything associated with the global maritime domain that could impact the security, safety, economy, or environment [54]. The National Information Exchange Model - Maritime (NIEM-M) XML vocabulary provides a combination of objects from NIEM core, the Maritime domain, and additions via the Enterprise Information Exchange Model (EIEEM) and IEPD, described later [53]. In order to fulfil the needs and requirements of the underwater domain, extension might have to be built.

Through the definition of IEPD standards, the NIEM-M provides a common vocabulary for data and information exchange in five initial focus areas [55] : Vessel Positions [56], Advance Notice of Arrival [57], Indicators and Notifications [58], Level Of Awareness [59] and finally Vessel Information [60]. Figure 4.1 presents the Information exchange models built using these IEPDs.

The technical representation of XML is complex and it can be difficult to track the relationship of NIEM and NIEM-Maritime components. To facilitate discussion and demonstrations with

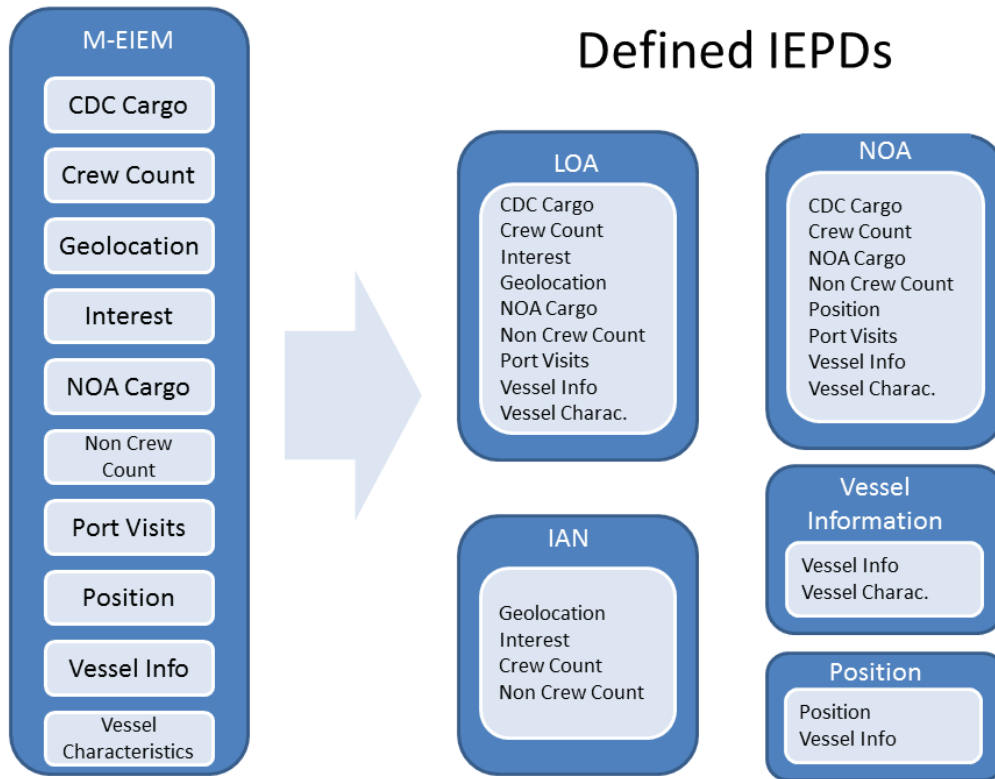


Figure 4.1: NIEM Information Exchange Models

business and process managers, a graphical representation of each data model has been developed [26]. Those graphical logical models representation can be found on [55].

Leveraging the security markings, such as the attributes in NIEM-Maritime based exchanges, a single data model can be used to support multiple versions of a product [26].

4.3.2 NATO Standard ISR Library Interface (STANAG 4559)

The diversity C4ISR systems in NATO Command, Control & Communications (C3) context is a fact of life which must be dealt with. Nonetheless, NATO’s policy is to achieve interoperability among all major systems [31]. Network-centric warfare concepts also imply broad interaction between systems [31].

The NATO Standard NATO Agreement (STANAG) 4559 NATO Standard ISR Library Interface (NSILI) is aimed at providing interoperable exchange of NATO ISR products among NATO accessible C4I Library Systems. The STANAG 4559 is the standard interface for querying and accessing heterogeneous product libraries maintained by various nations and revealed to partner nations as part of a coalition. It specifies a common software interface to be implemented and exist for all

NATO ISR interoperable systems.

The overall goal is for the users to have timely access to distributed ISR information if restrictions and security policies permit this access. Metadata are used for efficient cataloguing and narrow queries. The metadata is defined within the STANAG and gives information about the geolocation and the time when a product (e.g. an image) was acquired, the source of the data, security settings or product specific information (e.g. resolution) and based on this metadata, a user has the ability to query and subscribe to information that is of interest for him [32].

All the file products ordered are part of a defined NATO standard. The NSILI is being expanded in capability to discover and provide access to any type of ISR data, such as access to data in the following formats:

- STANAG 4545 NSIF;
- STANAG 4607 GMTI;
- STANAG 4609 Motion Imagery;
- STANAG 7023 Primary Imagery;
- STANAG 4633 NATO Common ELINT Reporting Format;
- STANAG 3377/3596 for reporting;
- MIL-STD 2500;
- ISO/IEC 12087-5 NSIF Profile of BIIF.

As mentioned in section 4.2.1, AUV data and information can readily be translated in some of these formats. As such, AUV data could be easily integrated in NSILI implementation, such as the Coalition Shared Data Server (CSD), which is described in the next section. This would ensure system interoperability at a coalition level for AUV data and data products.

4.3.2.1 Coalition Shared Data server

The CSD server, which is based on the STANAG 4559, provides a mechanism for distributed, searchable, persistent storage and retrieval of Joint ISR sensor data from heterogeneous sensors from different nations as well as exploited data and information, such as tracks and exploitation reports as well as tasking information and sensor data exploitation results [32].

Data in the common format is stored in the CSD and can be accessed by clients via the access mechanisms provided by STANAG 4559. The stored data consists of the actual ISR-data and a set of metadata that describes it. The metadata is defined within the STANAG and gives information about the geo-location and the time when a product (e.g. an image) was acquired, the source of the data, security settings or product specific information (e.g. resolution). Based on this metadata, a user has the ability to query and subscribe to information that is of interest for him. Over the standardized interfaces he can retrieve the information he needs depending on his role [61].

To make information available no matter where it is stored and where it is needed, the CSD concept envisions the near real-time synchronization of the metadata between different servers.

The information about products in the CSD is available in the whole network, regardless of where those products are stored. Each user needs to know only one access point, his local CSD, but has access to the whole data in the network (under the provision of granted access rights by the owner of the data) [32].

The data and information, as well as their describing metadata, which are stored within the CSD all follow a given standard to ensure interoperability between coalition members. As the employed sensor systems normally do not deliver the data in the standard formats, converters have to be developed that translate the incoming data into a common data format. Figure 4.2 shows the different NATO standards used within a compliant CSD.

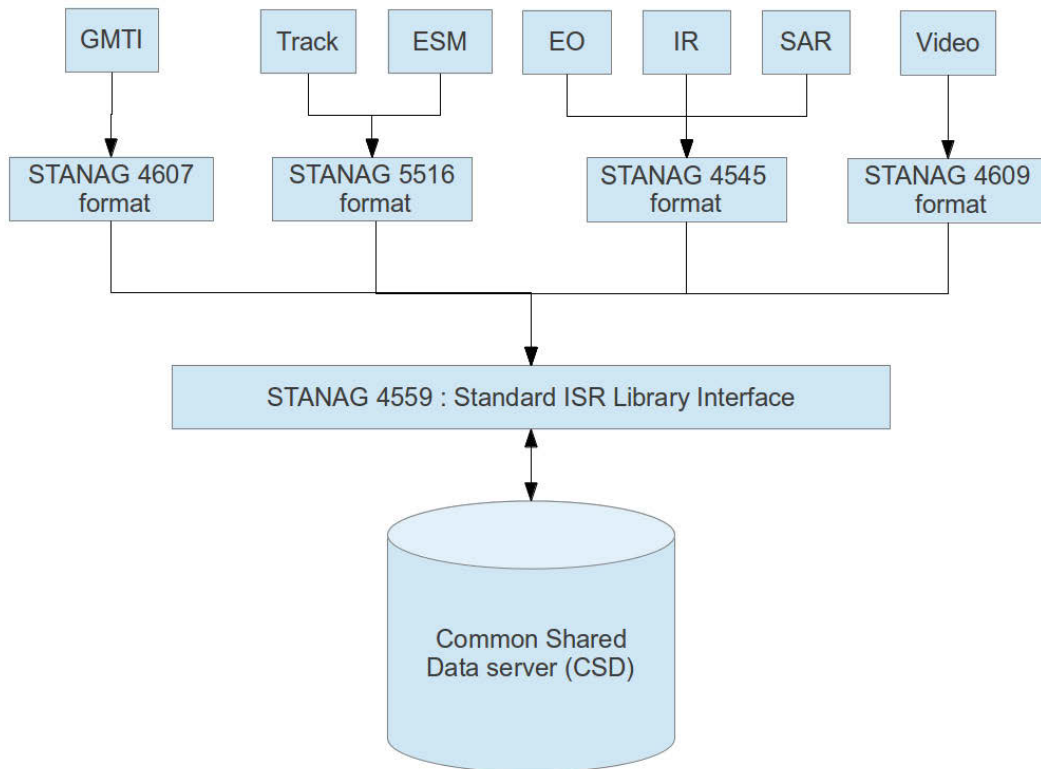


Figure 4.2: STANAGs based interoperability.

In order to integrate most of the possible AUV payloads, some other STANAGs would be necessary, but the existing ones can still be used as basic building blocks to start integrating AUV in coalition-based operations.

4.3.3 Joint C3 Information Exchange Data Model

The Joint C3 Information Exchange Data Model (JC3IEDM), which is a model that when physically implemented aims to enable the interoperability of systems and projects required to share

Command and Control (C2) information [28], was produced by the Multilateral Interoperability Programme (MIP). The aim of the MIP is to achieve international interoperability of Command and Control (C2) Systems at all levels from corps to battalion, or lowest appropriate level, in order to support multinational (including NATO), combined and joint operations and the advancement of digitization in the international arena [28].

JC3IEDM a fully documented standard for an information exchange data model for the sharing of C2 information. The model defines the standard elements of information that form the basis for interoperability between automated Command and Control Information Systems (C2ISs) that accommodate the model's information structure [62].

As with the NIEM, the focus of JC3IEDM is on data interchange, not the data models employed by the individual systems. The JC3IEDM defines a core model to which users can apply extensions [63]. The model serves as a coherent basis for information exchange applications within functional user communities. The general pattern is to use a subset of JC3IEDM and add functional extensions [62].

The scope of the JC3IEDM is directed at producing a corporate view of the data that reflects the multinational military information exchange requirements for multiple echelons in joint/combined wartime and crisis response operations. The data model is focused on information that supports:

1. Situational awareness
2. Operational planning
3. Execution
4. Reporting

Use of free text is to be minimized, since there cannot be an agreed understanding of most textual content, and textual content is generally not subject to automated processing by a C2 system [62]. The JC3IEDM in its current form also has some serious shortcomings [31] :

- It is very large and complex. This makes it hard to comprehend, implement and maintain. It contains 195 entities, 785 attributes and 277 relations. The accompanying documentation with definitions, domain specifications, etc. takes over 1000 pages;
- A slow decision process caused by several factors, among which the large number of nations involved, the models complexity and national issues;
- There are several structural aspects in JC3IEDM which cause certain problems. The model is partly too generic or too explicit, is not denormalised at the physical level, contains metadata and static data and is little integrated with unstructured information.

During analysis phase of the transition to the JC3IEDM, it was discovered that there were no provisions for representing the idea of metadata. As military digitized C2 system capabilities continue to mature, it would seem appropriate for NATO countries to consider how to incorporate metadata into the current and future JC3IEDM data model [64]. Also, the JC3IEDM is a good example of an IEDM that has a scope which has become far too wide[31].

4.4 Summary

This section presented the standards of interest related to the UUV domain. The data formats for the different sensors are well accepted and understood by the user community. However, the use of a more high-level standard such as SensorML would have some benefits over some low level standard for certain data types.

In terms of information exchange models for interoperability, the use of NIEM should be the way forward. The U.S. DoD has now committed itself to fully support this standard for multi-agency interoperability and it would be ill-advised not to follow. NIEM offers several benefits over the other information exchange data models. A lot of support is available and it offer the flexibility needed to gracefully evolve in the future. However, CSD support should not be overlooked as interoperability within a international coalition might require this technology. An approach that allows the integration and interaction of both information sharing mechanisms might be an alternative.

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Part 5

UUV Information and its integration in ashore systems

The overall objective of gathering underwater data from a UUV is to integrate sea surface and undersea surveillance with land and air monitoring in the interests of an effective understanding of activities and events that could affect Canada's security, safety, economy and environment [12]. Data from underwater sensors will be sent to the Maritime Security Operations Centres (MSOC), to be correlated and formatted and then passed along to relevant agencies for overall maritime domain awareness.

However, such integration is facing many challenges. First, data transmission from a UUV is not as easy as radio broadcasting when using a UAV. Then, if the data transmission is not real-time, the problem of information latency arises. Also, how is this information likely to be distributed amongst community of interest? What are the additional requirements on existing persons and infrastructures if UUVs are to be integrated to contribute to the enhancement of the MDA?

This section presents different aspects regarding the integration of data and information produced by UUVs to task groups or ashore systems. This section is organized as follows:

- Section 5.1, presents possible options for UUV communications. These are highly related to the type of missions and applications for which the UUV is used.
- Section 5.2 describes ways of distributing UUV data and information to task group and ashore systems with a particular focus on coalition and multi-agency interoperability.
- Section 5.3 discusses the latency problem of UUV related data and its potential impact on its integration in information systems.
- Section 5.4 presents the contribution of data and information from UUVs to maritime domain awareness.
- Finally, 5.5 discusses additional requirements that may be placed on people, systems and communications should UUVs be integrated to contribute to the overall maritime domain awareness.

5.1 Communication with ashore systems

Buoys, AUVs at the surface, small Unmanned Surface Vehicle (USV)s, and other assets, operate with extensive data acquisition capability. In many applications, it is desirable to have fast (or real-time) transmission of the data to command and control stations in operations centers onshore or in mother-ships. Examples are surveillance, inspection and monitoring missions where operator interaction is needed to analyze the data, get situation awareness, make decisions, and execute tasks based on analysis of the data [65].

However, in some other applications, such as oceanography for seabed mapping or other environmental applications, real-time communication is not as critical. Therefore, the strategy for data and information retrieval from a UUV is mission dependent.

Once submerged, as radio frequencies do not propagate well in seawater, information transfer between the vehicle and the operator becomes both critical and difficult. The shallow water environment is also especially challenging to acoustic communications.

Typically, any UUV is equipped with the following communication payload [65] :

- Radio Frequency Wi-Fi : short range communication system used at-sea, on-deck and "in the shop".
- Iridium SATCOM : low data rate near global communication method.
- Two-Way Acoustic Telemetry/Modem.

Using this equipment, data and information gathered by a UUV can be transmitted back to ashore systems in three different ways.

- UUV recovery followed by data retrieval and processing.
- UUV resurfacing and broadcasting data via satellite communication or to an Unmanned Aerial Vehicle (UAV) or a surface platform nearby (buoy, ship, unmanned surface vehicle, etc...).
- Data transmission via an underwater communication network of static and/or mobile nodes until it reaches a surface platform.

Each of these communication options has its interest depending on the situation and ongoing mission. A trade-off needs to be reached in terms of the amount and rate of information to be relayed by the AUV and covertness of the mission versus the latency of the information that can be tolerated for that mission. However, latency might be reduce and near real-time monitoring might be achieved if the UUV is configured to surface and broadcast when it detects an object of interest (especially in the context of ASW and ISR).

Deploying underwater sensors that record data during the monitoring mission, and then recovering the instruments has the following disadvantages ([66],[67]):

- No real-time monitoring : this is critical especially in surveillance or in environmental monitoring applications such as seismic monitoring. The recorded data cannot be accessed until the instruments are recovered, which may happen several months after the beginning of the monitoring mission.
- No on-line system reconfiguration : this impedes any adaptive tuning of the instruments, nor is it possible to reconfigure the system after particular events occur.
- No failure detection : this can easily lead to the complete failure of a monitoring mission.
- Limited storage capacity.

For oceanographic missions related to undersea mapping for bathymetric chart creation, this method of data transmission is well suited as it is not time critical and the mission parameters are well known.

An underwater network might consist of any type of UUV, and other various sensor nodes (either released from surface platforms or moored). These surface platforms (if not prevented due to restrictions imposed by tactical conditions) might serve as gateways and provide radio communication links to on-shore stations.

The use of a satellite communication link is a common approach, but this has limitations due to only partial satellite coverage, as well as relatively high costs and relatively low data rate [65]. Satellite phone expenses can make up a significant portion of an AUV's operating budget during long missions [8].

Experiments were conducted by [65] in which the data were downloaded from the AUV through the UAV communication relay to a ground station. The result shows that at the tested (typical) flight conditions the distance and attitude between the AUV and UAV are not the bottlenecks in the communication network. The main bottleneck was identified as the capacity of the proprietary wireless system on the AUV, in this case a REMUS 100, which seemed to be set up to provide a relatively low capacity wireless data link regardless of signal strength and quality [65].

5.2 Information decimation and distribution

Figure 5.1 (from [68]) presents the usual data flow of data gathered by an underwater vehicle along with the data standards at each point.

Data decimation may occur prior to or during transmission. It is recommended in the literature that the data should not be decimated. However, if the acquired data was to be decimated, this decimation must be reflected in the metadata. As mentioned in [16], if averaging, sub-sampling of the data, or other data processing method is used, the method should be fully described by the metadata. This is usually part of the data quality metadata.

Ocean Networks Canada provides a good example of decimation annotation in the metadata for oceanographic products [69]. They too meet the guidelines of the Quality Assurance of Real Time Oceanographic Data (QARTOD) group. QARTOD is a US organization tasked with identifying

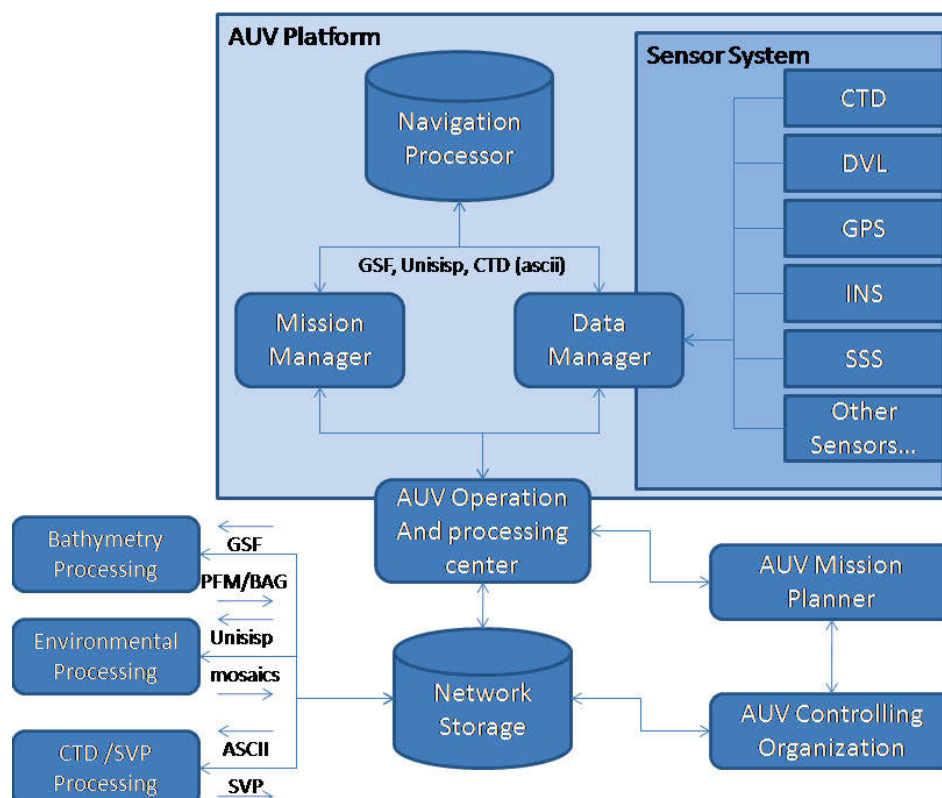


Figure 5.1: Typical AUV data flow

issues involved with incoming real-time data from the U.S Integrated Ocean Observing System (IOOS). A large portion of their agenda is to create guidelines for how the quality of real-time data is to be determined and reported to the scientific community [69]. Amongst the data quality flags in the metadata, there is one for a data set consisting of averaged values.

For oceanographic data, QARTOD defines the following data management guidelines [69]:

1. Every real-time observation distributed to the ocean community must be accompanied by a quality descriptor.
2. All observations should be subject to some level of automated real-time quality test.
3. Quality flags and quality test descriptions must be sufficiently described in the accompanying metadata.
4. Observers should independently verify or calibrate a sensor before deployment.
5. Observers should describe their method / calibration in the real-time metadata.
6. Observers should quantify the level of calibration accuracy and the associated expected error bounds.
7. Manual checks on the automated procedures, the real-time data collected and the status of

the observing system must be provided by the observer on a timescale appropriate to ensure the integrity of the observing system.

Following those guidelines should ensure that the data consumer is aware of the quality of the data he is receiving. As such, the usage should reflect that quality. Listing 5.1 presents an example of the metadata for a decimated product (XML listing courtesy of VENUS Coastal Network, Ocean Networks Canada).

Listing 5.1: Metadata for data quality

```

1 <dataqual>
2   <attracc>
3     <attraccr>
4       Devices are routinely calibrated and instruments measure within the
5         manufacturer specifications unless otherwise noted. Please contact
6         us for calibration information.
7     </attraccr>
8   </attracc>
9   ...
10  <complete>
11    <completesub>
12      The data in this dataset is a bin average of many points. No gap
13      information to display
14    </completesub>
15  </complete>
16  <posacc>
17    <horizpa>
18      <horizpar>
19        0.0000179 decimal degrees latitude and 0.0000271 decimal degrees longitude
20      </horizpar>
21    </horizpa>
22    <vertacc>
23      <vertaccr>1 meter</vertaccr>
24    </vertacc>
25  </posacc>
26  <lineage>
27    <procstep>
28      <procdesc>
29        <prosub>
30          This dataset has been bin averaged into 60 minute intervals. The
31            number of values and the standard deviation for each value
32            are given with the data. Also given is the mean timestamp of
33            each bin.
34          </prosub>
35        </procdesc>
36      </procstep>
37    </lineage>
38  </dataqual>

```

5.2.1 Metadata distribution and information discovery

Once collected and processed, the data and information need to be made available to various agencies for further analysis or its integration in various systems.

According to the Net-centric Data Strategy, data/information needs to be :

1. Visible : achieved with the use of appropriate metadata tagging and discovery tools;
2. Accessible : achieved by storing data and information in standard formats and on shared spaces accessible via URL;
3. Understandable : achieved through the use of a common vocabulary.

The data visibility is achieved through the appropriate use of metadata to describe the data set along with the necessary automated tools for discovery. It is recommended that a minimum set of metadata that transcends all UUV sensor types be developed and that generally, metadata must align with the Federal Geographic Data Committee (FGDC) Metadata Content Standard, as well as the extensions for remotely sensed data [16].

A good example for underwater oceanographic data discovery and distribution is Oceans 2.0 component part of the Smart Oceans Systems ([70]). Oceans 2.0 a unique and critical component developed to connect the subsea instruments systems, providing the capability for the 24/7 acquisition of extremely diverse and vast amounts of data, quality control and calibration, storage, visualization and access by a potentially global audience, as well as providing a convenient interface to handle otherwise complex tasks associated with the remote monitoring and control of the observatory infrastructure itself [71]. In addition, their data follow the FGDC international metadata standards.

Despite this system being quite good, the data distribution and discovery is specifically tailored for the oceanographic community. In order to be used by multiple agencies, it should use an IEDM. That means that some of the metadata for the data and information would have to be modified to support a common core vocabulary, such as the NIEM-Core for example. Also, IEDP would have to be developed based on the requirements of the information exchange.

Figure 5.2 represents a concept of data discovery and distribution based on the previously presented NIEM and CSD concept.

As an example, a CBRNE detection, both the Emergency and CBRN communities are concerned with such a detection. From the same source event, a CBRNE detection, two discrete events would be created : an Alarm event in the Emergency community and CBRNE detection event in the CBRN COI. Therefore, the use of the publish/subscribe mechanism of NIEM and the correct IEPD for each COI ensure that all the involved agencies would have received the right data, described with the correct vocabulary.

In addition, CSD support must remain an option for multinational military coalition. NATO countries will likely still base the exchange of data and information from UAV on that technology since it is based on adopted standards and it has been tested and proven on several occasions. However, in order to support interoperability with non-military agencies, the alternative is to use

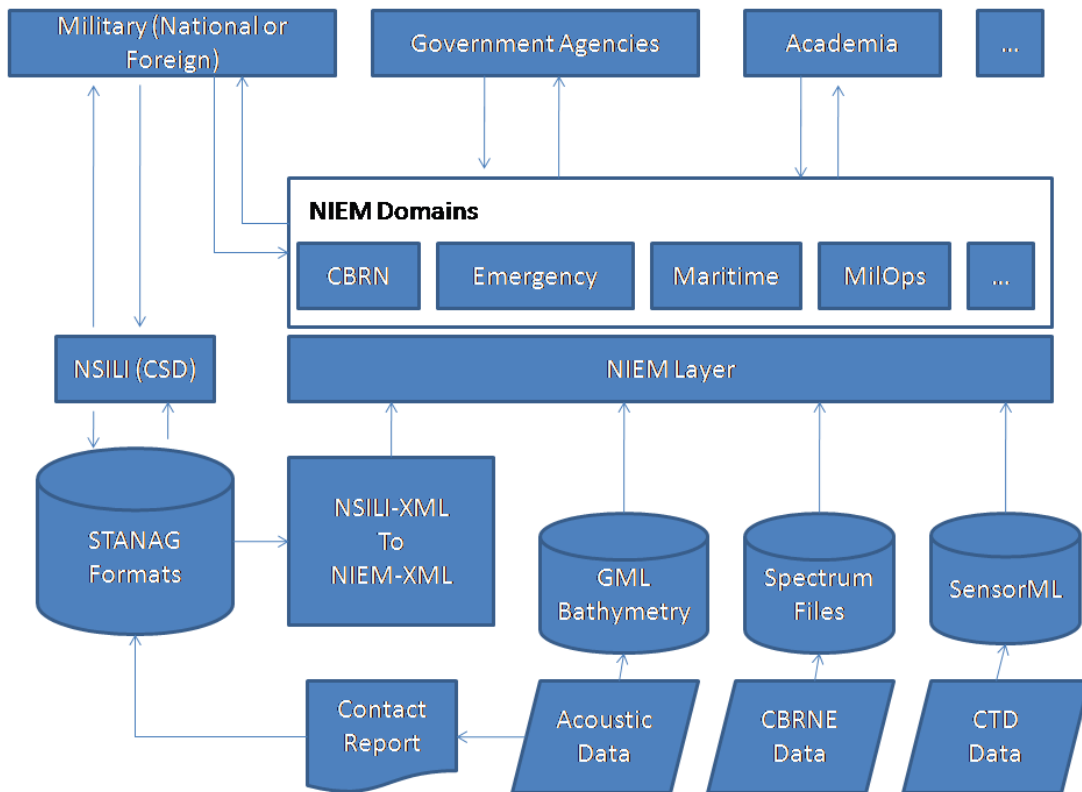


Figure 5.2: AUV data sharing concept

NIEM which can interact with the CSD and provides the flexibility and low learning curve that are necessary for a wide-spread adoption and usage.

5.3 Data/information latency and its impact

Latency in data is in direct relationship with the underlying mission.

There are two overall approaches of collecting underwater information. First is when the UUV gathers data for a long period of time, surfaces and transmits. In such a case the latency might be counted in weeks. This is often the case for oceanography.

The other case, likely more ASW or certain subcases of ISR is when the UUV detects something of interest or monitors an area of interest.

In each case appropriate methods for transmitting the information within the acceptable latency limits for the specific mission need to be planned as part of the mission design, from:

1. UUV reaching the surface and transmitting (usually long endurance UUV),

2. UUV with an acoustic modem communicating with a surface buoy or surface station broadcasting the information via an established satellite (or other telecommunication) link,
3. Via an underwater sensor network that uses a combination of acoustic, optical and ultrasound communication to relay the information to the surface [72],
4. A swarm of UUVs, each one serving as a communication relay. Where one of the nodes might have a cable reaching a surface ship.

In each mission a trade-off analysis needs to be performed in terms of the amount and rate of information to be collected and relayed by the AUV and covertness of the mission versus the latency of the information that can be tolerated in the methods and algorithms building the situational awareness appropriate for that mission.

In the first method the latency can be counted in minutes or less, depending on the vehicle type and its design (depth of operation and time to reach surface and broadcast). This is appropriate when the covertness of the mission is not necessary to maintain and this also implies that the situation is not adversarial, and latencies of minutes can be tolerated.

In the other 3 methods, near real-time of few seconds delay might be possible depending on communication time undersea using an acoustic modem or other means of communication. Such methods of communication are appropriate also in covert missions, although there is flexibility to design configurations that collect information for any type of missions. The choice of the specific configuration depends on the dimension, depth and other characteristics of the area that is being surveyed, the type of sensor payloads necessary for that mission, the amount of information that these sensors need to collect to support the specific mission, the latency that can be tolerated within the constraints of the supporting infrastructure and resources that can be available to that mission.

There are numerous unique challenges that influence underwater node and sensor configuration and routing protocol design as well as different underwater communication architectures, which will impact the latency of information collected and made available for the mission. Some examples of such challenges include:

- Underwater acoustic communication depends not only on the distance between the transmitter and receiver, as is the case in many other wireless channels, but also on the signal frequency, which determines the absorption loss which occurs because of the transfer of acoustic energy into heat,
- Acoustic communication is impacted by multi-path propagation, time variation of acoustic channel, thermocline, strong signal attenuation and high error rate [15]
- Underwater optical communication is point-to-point and only for short distances, while ultrasound communication can be broadcast, but is very slow [72]

Such challenges have to be carefully considered in the design of the UUV configuration design for a mission to ensure that the delivery of information is within tolerable latencies for a mission. However at the same time the methods and algorithms building the MDA have to be designed to be able to recover from delays in information delivery.

5.3.1 Impact of latency on MDA

As explained above, the configuration of the host platform and the underwater network design (if any) should be tuned to achieve latencies that can be tolerated in each mission.

Some examples of the impact of information latency in some missions identified in section 2.2 are discussed below.

In some oceanography/hydrography missions (e.g. bathymetry or sub-bottom profiling) usually the information is collected over long periods of time, and the impact of information latency in most cases can be minimal.

In other oceanography/hydrography missions for example missions like water column characterization, ocean current profiles, temperature profiles, salinity profiles, the information collected helps calibrate acoustic information transmission specifics. This information is used by acoustic subsystems to estimate geolocation and uncertainties of underwater detections. Latencies and unavailability of such oceanography/hydrography information can impact accurate estimation of MDA in all missions.

The methods and approaches building the MDA cumulatively integrate information available to them from all sources, including from UUVs, when used. The modern methods take uncertainties and latencies (of certain extent) into account. The modern methods also provide techniques to correct the situational picture with latent information (out of sync detection processing, e.g. retrodiction). To be able to use these modern methods, it is necessary to make sure that the messages transmitted by the UUVs include meta-data comprising additional information, like time of detection, the detecting UUV geolocation, the sensor characteristics information, etc. The existing information exchange protocols need to be carefully analyzed to ensure that provisions are made to collect and include the necessary meta-data that will help recover from latent information ensuring a more complete and accurate MDA.

The need for such analyses is already identified in the existing exchange protocols. For example, in STANAG 4586 for those data where unknown latency may cause a problem, it is recommended that a 'time of validity' also be included in the private message indicating the time of validity of the data. Also the Sensor Model Language (SensorML) includes significant meta-data detail about the observations, although it is designed for low data rates.

Overall, some of the information exchange methods described in section 4.2 are designed to support meta-data detail better than others, some are easier to use than others, different ones support a sub-set of sensor payloads and meta-data.

During the design of each mission the MDA requirements, the available information sources and exchange protocols, information analysis/fusion approaches as well as tolerable latencies and other information quality attributes need to be analysed as a whole to ensure optimal situational awareness. It is clear that such holistic design of the mission is especially critical in missions like ASW, MCM, CBRNE where in certain situations any latencies in the collected information can lead to very grave consequences.

There needs to be continuous dialog between the decision support development efforts for the

establishment of MDA and the information exchange standardization organizations to ensure that these organizations have good visibility and understanding for the information and meta-data requirements for establishing the MDA, ensuring that the standards evolve accordingly.

5.4 Information integration / fusion to support MDA

The sections above describe a variety of configurations for using UUVs and AUVs in various missions. The figure 5.3 [73] shows a typical mission where a large number of AUVs and a variety of communication methods are used to collect information for the establishment of MDA that could be appropriate for an ASW or ISR mission. An oceanography/hydrography mission would most likely be set-up to have a similar configuration, with possibly less elaborate communication exchange requirements in many types of operations.

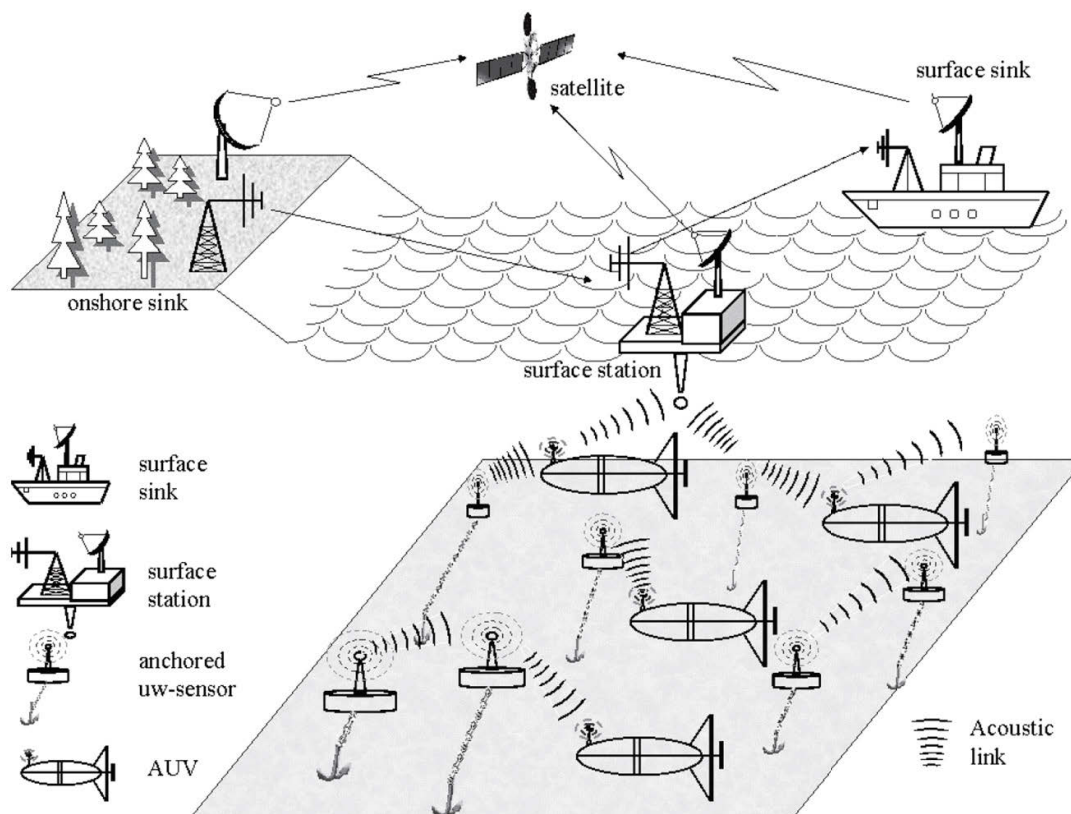


Figure 5.3: Typical UUV/AUV Mission

In terms of integration/fusion to establish situational awareness to achieve the goals of the mission, the problem amounts to the same analysis and processing phases shown in figure 5.4 with appropriate analyses for the specific mission in each phase. Note that the diagram details only the Observe part of the Observe, Orient Decide Act (OODA) loop of the overall fusion system. Orient, Decide and Act phases of any mission are performed by humans using decision support

tools. The technologies for this part of the OODA loop are much less mature and in most current systems humans perform most of the analysis and decision making. In the figure the AUV/UUV Control component encapsulates the Orient, Decide and Act processing that directly applies to the management and control of the UUVs in the mission.

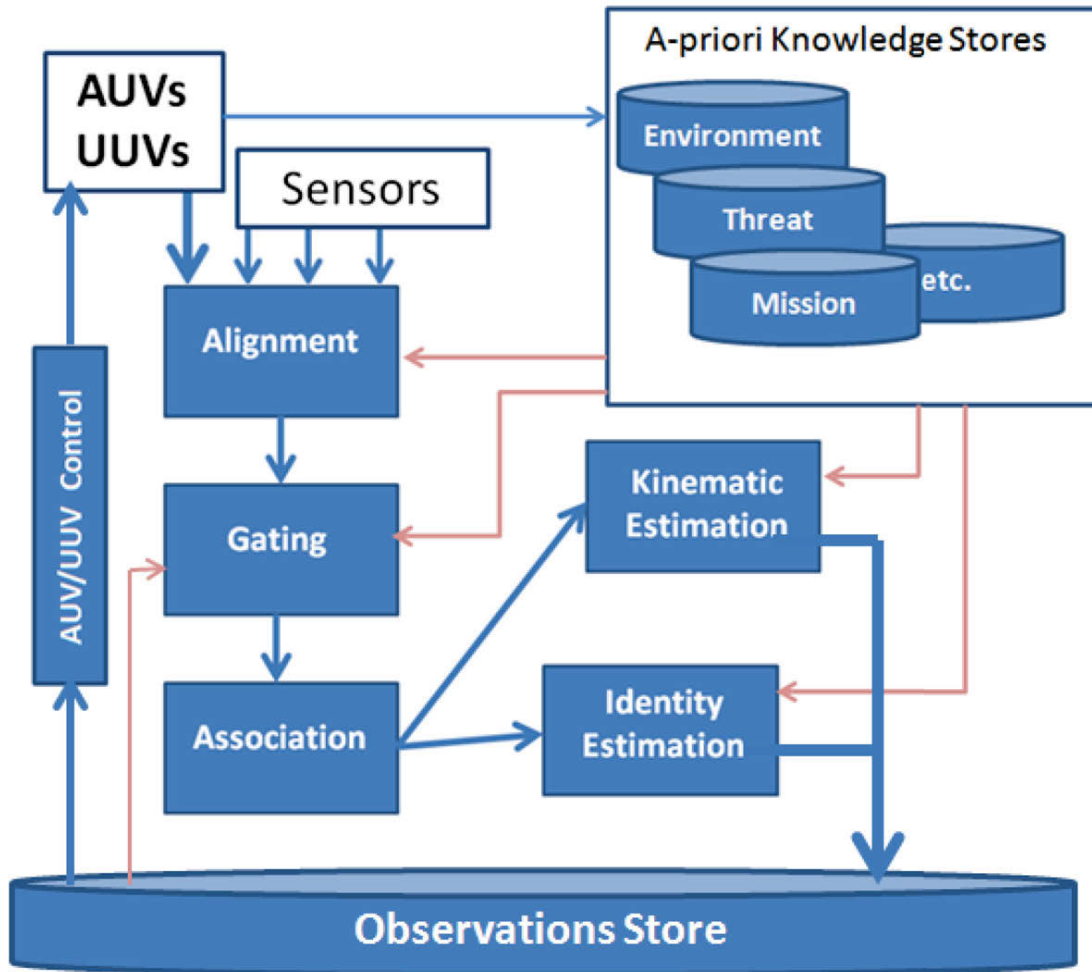


Figure 5.4: High Level Diagram of Fusion Processes in UUV Missions

The design of the mission should include a number of analyses regarding the architecture of the fusion system, including:

- Is there pre-processing of the information in the UUV and to what level
- If there are more than one UUV is there one central processing engine integrating/analysing the information from all UUVs before being fused with other information sources contributing into the MDA?
- What level of control should there be over the UUVs and what information is the decision support for the control of the UUVs based on?

- How are the A-priori knowledge stores maintained and updated?

Theoretically the fusion result will be of far higher precision if UUVs are able to provide all their unprocessed detections to the fusion centre in real-time. However considering the added difficulties of underwater communication (compared to the above water), in most cases it is realistic to assume that certain level of pre-processing will take place in the UUVs. If more than one UUV and/or underwater sensors are used in the mission, an underwater information integration would be performed in one of the UUVs (or any underwater pre-processing centre with some fast communication link with the UUVs).

The analysis of the underwater information preprocessing requirements versus the communication infrastructure, versus the tolerable latencies and versus the tolerable level of precision of the resulting fused situational awareness have to be made in the design of each mission. The choice of methods and algorithms in each fusion process in figure 5.4 will be impacted by these design decisions keeping the functionality and output products specific to the process. A short description of functionality in each of these processes is provided below identifying more challenging issues when fusing UUV data.

In the Alignment process the incoming information must be transformed into a common reference frame and coordinate system and in a format that is understood by the other fusion processes.

For positional data, alignment can:

- Refine and extend in time the estimates of an object's position - dead reckoning and correction (time alignment)
- Transform sensor data into a consistent set of units and coordinates - rotation and translation, triangulation, (spatial alignment)
- Extrapolate data using various estimation techniques applied on history of same type of data
- Evaluate latencies and assess uncertainties for retrodiction processing
- Assess uncertainties for data that are received without this information
- Perform necessary de-correlation processing for cross-correlated pre-processed information

For attribute data, alignment can:

- Calibrate any information that can be used as attributes for classification (size, frequency, colour, imaging features, chemicals, etc.)
- Translate attributes into ID propositions (based on a-priori knowledge of what observations (mines, submarines, pollutants, marine life, etc.) we expect to make during the mission)
- Combine various information from sensors that provide complex reports
- Assess the confidence level for data that are received without this information.

Note that the assessment of the confidence level in both position and attribute alignment is only necessary when such meta-data has not been received, which is often the case with many legacy sensor interfaces.

The first challenge in positional alignment of underwater detections is due to the fact that there are additional uncertainties caused by underwater information transmission calibration due to multi-path propagation, time variation of acoustic channel, thermocline, strong signal attenuation, etc.. On one hand the objects under water move slower than above water, hence some positional data alignment estimations for missions where UUV reports are being received frequently will not depend on positional displacement over time, but mainly will depend on the quality of the oceanography/hydrography information used (how current and accurate) to calibrate the underwater detections. However in missions where the UUV reports are not frequent the positional alignment of the UUV information becomes very challenging, also due to the uncertainties of movements of the objects over time. The other challenge of positional alignment of UUV data is the fact that the information received will most likely be pre-processed and will require de-correlation processing. Ideally if the UUV data included covariance information from the pre-processing, the de-corelation processing would be relatively simple. However most current information exchange standards (legacy systems) do not have provisions for such information, and approximate estimates of uncertainties will be more challenging for underwater information.

The aim of the attribute data alignment is to prepare and convert the observations made by the UUV subsystem of the mission (as shown in figure 5.3) to the form that the identity estimation algebra will use. The type of information received will be very much mission dependent, and the specific preparation/conversion performed will depend on the identity estimation algebra selected for the fusion system.

For example, assuming a Dempster-Shafer evidential reasoning approach is selected for attribute estimation, in a CBRNE mission, the UUV reports will contain chemical, biological, etc. detections, the a-priori knowledge stores would contain attributes of any type of CBRNE threats that can exist, and the attribute data alignment would build propositions regarding to which CBRNE threats the detections made by the UUV CBRNE payloads can correspond to. Similarly, for ASW missions the UUV reports will include detections of various attributes of underwater objects, the a-priori knowledge stores would contain any type of attributes that is possible to detect to identify all known submarines and other underwater objects, and the attribute data alignment would build propositions regarding to which submarines and other underwater objects the UUV detections can belong to.

The goal of the Gating and Association processes is to match kinematic, attribute, or time history data to the appropriate observations/tracks to allow the application of statistical estimation techniques. In some data/information fusion implementations, gating is included within the association processing.

Gating is a technique used to withdraw the unlikely associations between the detection from the sensors and UUVs and the observations (in the stores). A gate is usually a hyper-ellipsoid (it has the dimension of the state vector) surrounding the predicted contact. The use of a gate, with certain rules of selection, increases the performance of the filter and avoids spurious associations (e.g. a specific detection cannot be observed for a submarine). Gating ensures that the subsequent association and estimation processes have to deal with a smaller, but more consistent subset of

detection to observation pairs. Considering the increased uncertainties and anticipated latencies in underwater detections, it is important to design the gating algorithms that take characteristics of the specific sensor payloads and latencies into account to ensure that most of the spurious detections are eliminated.

Association measures (provides a score) the degree of similitude given two sets of information (one from the sensor (detection) and one from the observations/tracks). It also decides which similitude is the best (assignment). The output from this process is a list of detection to observation pairs, a list of proposed new observations and a list of unassociated observations (no new detections against these observations have received). With a sophisticated gating method preceding the association, a simpler association algorithm can be used successfully.

Kinematics Estimation is a statistical process used to evaluate the kinematics of a static or dynamic target based on collected detections/measurements. The kinematics refers to the position, velocity and acceleration of an object in space. The kinematics estimate of an object is normally implemented with linear statistical estimators. Here too, when estimating kinematics of slow moving underwater objects (with not very excessive latencies) under observation by UUVs, a simple estimation algorithm can be successfully used (after gating and association). However it is also possible to chose multi-hypothesis or particle filtering fusion approaches that process all available information synergically (without pre-processing or clean-up of unlikely associations). While these methods theoretically produce a more optimal estimated target kinematics, they are much more complex and risky. The models of uncertainties, latencies as well as the specifics of pre-processing of the underwater detections in the UUV reports will need to be understood with as much precision as possible and accounted for in such fusion approaches, leading to even higher complexity and risk.

Attribute Estimation can be done using many different approaches including neural nets, pattern recognition, knowledge based and rule based, fuzzy logic and statistical based algorithms. Typical attribute data are not variable on a continuum as are the positional data, but are subjective information to which a probability value or a level of confidence is assigned (in the alignment phase). The role of the target attribute estimation and fusion process is to provide the necessary algebra in order to manipulate the evidence and extract the identity of the entity under observation with an appropriate level of confidence. The choice of the approach chosen for Attribute Estimation and the processing for the alignment depend on the nature of the information collected by the payload of the UUVs in a mission.

Continuing the examples discussed above for attribute data alignment, in a CBRNE mission, the Dempster-Shafer evidential reasoning approach would derive belief and plausibility estimates for which CBRNE threats the UUV detections can be attributed to. Same example applies to attribute estimation in any other mission.

In addition to the sensor and UUV information and the situational picture stored in the Observations Store, there are a number of types of additional information that the fusion processes need to produce their output products (association assignments, estimations, etc.) Examples of such information are environmental conditions, oceanography/hydrography information, a detailed list of prior knowledge of what type of attribute information can be observed with all the sensors (in UUVs and other) that provide detections in the mission, mission specific geolocal plans, sensor specific data like uncertainties, and other parameters etc. Such information is included in

the a-priori knowledge stores.

In summary, depending on the level of pre-processing performed in the information sources (sensors and in the UUVs) the algorithms in gating, association and estimation processes will have different degree of complexity and will produce estimates of different degree of precision. Theoretically, synergies between the information sources can be much better utilised if fusing un-processed information, as the pre-processing reduces and removes some of the details about the detections, however the approaches and algorithms necessary to fuse unprocessed information are likely to be significantly more complex. This implies high risk and high developmental costs, and again the mission design will have to include the trade-off analysis of risks versus optimal situational awareness for the mission.

Depending on the mission, there will be necessity to manage/control the UUVs. The AUV/UUV Control process will monitor the information collection and pre-processing (if any) within the UUVs together with the estimates derived by the fusion system and make a number of actions/decisions including:

- Direct the UUVs to swim to other locations
- Detect and transmit specific data in addition to pre-defined communication schedule
- Cue the pre-processing algorithms with fusion results, enhancing their performance

GLINT09 sea trial performed by NATO Undersea Research Center (NURC) between the 29th June and the 18th July 2009 [7] and [74] has successfully demonstrated a successful execution of an ASW mission with fusion capability, with multiple communicating UUVs performing acoustic signal processing with ability to carry out the necessary change to behaviour or position to optimise the chance of detection and classification and to minimise the errors in localisation.

The project as a whole incorporated research into both AUV control for ASW and the issues of how networking and underwater communications can be used to facilitate system wide detection and localisation as well as passing information back to a centralised command centre [74].

The above description of the fusion capabilities is very generic, leaving the design of specific processing with the mission designers. In each of the missions (ASW, MCM, ISR and CBRNE) detections by the sensors in the UUVs, the information pre-processing as well as the other information sources will provide appropriate information for that mission, the a-priori knowledge will pertain to the mission and the fusion processes will have to be selected to optimize the Situation Awareness (SA) and MDA.

5.5 Additional requirements on people, systems and communications

The discussions above have in many places identified the requirements on people, systems and communications. The integration of UUV-collected information is likely to put additional requirements at several levels such as :

- Person;
- Communication;
- and Systems.

The standardization at the data and information exchange level will require that on one hand people keep abreast of information and meta-data requirements of modern information systems that develop and provide situational awareness and ensure that the standards are able to provide all necessary information and on the other hand that people are aware of the common vocabulary used in the metadata and data products itself to request and use data and information products correctly. The learning curve to use these standards should not be that high as people from the different community of interest should already possess most of the required knowledge.

At the communication level, the new requirements will emerge from the missions in which the UUVs will be used. If those missions require that the information be available in a near real-time manner, then in the near term new communication relays must be added close to the location of operations to ensure timely information availability and on longer term emphasis needs to be put on research on improved performance and robustness of underwater communication capabilities.

The need to support data and information exchange standards, such as NIEM, will create new requirements at the system level. Information exchange requirements will need to be carefully identified. This will lead to the reuse and / or creation of new information exchange package. Middleware and software services will have to be developed to enable data and information discovery and exchange between various agencies and organizations if UUV-collected data are to be used in a truly interoperable fashion.

In a machine-to-machine information exchange context, currently used systems will need to be updated to automatically process standardize information in time critical applications such as emergency management and response.

Part 6

Conclusion

This document provides the results of the research to better understand how UUV-collected information may be used to describe the overall maritime situation, thereby providing improved knowledge and improved MDA. To achieve a better understanding of both the information content and the information architecture that supports the data/information that may be obtained from sensors onboard an UUV, and how this information might support MDA a literature survey has been conducted and analysed from a number of perspectives:

- To identify and build an understanding of different missions and applications in which UUVs played an essential role in collecting data and deriving information contributing to MDA. In the specific context of Canada, multiple missions have been identified the benefit from the integration of UUV as a data gathering platform. ISR, ASW and oceanography missions are amongst the ones with most expected military, economic and academic benefits.
- To identify existing sensor payloads that support these missions. Developed an understanding of acoustic and CTD sensors that are already widely used and CBRNE detection sensors that are starting to be fielded and their use is expected to grow in the coming years.
- To identify the standards used for sharing the information between multiple agencies and organizations, and data formats and data/information discovery and sharing approaches. Developed an understanding of the currently known and adopted data formats for encoding in the underwater community of interest as well as the software and data sharing infrastructures that are already available but lack the use of an information sharing standard for cross-domain interoperability, required if one wants to optimize the use of the information, ensuring that it reaches its full potential for a broad range of missions.
- To evaluate approaches for to correctly integrating such data and information with regards of some challenges specific to the UUV domain. Analyses of how the information can be successfully used considering the difficult and slow communication rate as well information latency aspects.
- To identify how does the information discovery, distribution, or exploitation place additional requirements on the system or people or metadata.

The collected literature emphasized the numerous benefits of employing UUV technology in various missions, especially in Canada with its vast coastal areas. UUVs can be effectively deployed in missions in shallow-water littoral regions as well as in remote environments, where deploying personnel is a very costly alternatives. The UUV use has been demonstrated to be very cost-effective with persistence and data quality that are not achievable using traditional methods.

However, in order to be exploit maximum benefits from employing the information collected by UUVs in the establishment of the situational awareness the mission design needs to be analysed in terms not only the UUV design with appropriate sensor payloads, but also how the information is integrated with data from other information sources within the processing centre.

Precise identification of mission requirements must be made and a trade-off analysis of communications possibility versus acceptable information latency has to be conducted when using a UUV, especially in remote locations where communication infrastructure is less developed. Then a trade-off analysis of methods and approaches for integrating the information needs to be performed in terms of the latencies, amount and rate of information that will be available from the UUV and other sources versus the quality of estimated situational picture necessary to support the requirements of the mission.

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