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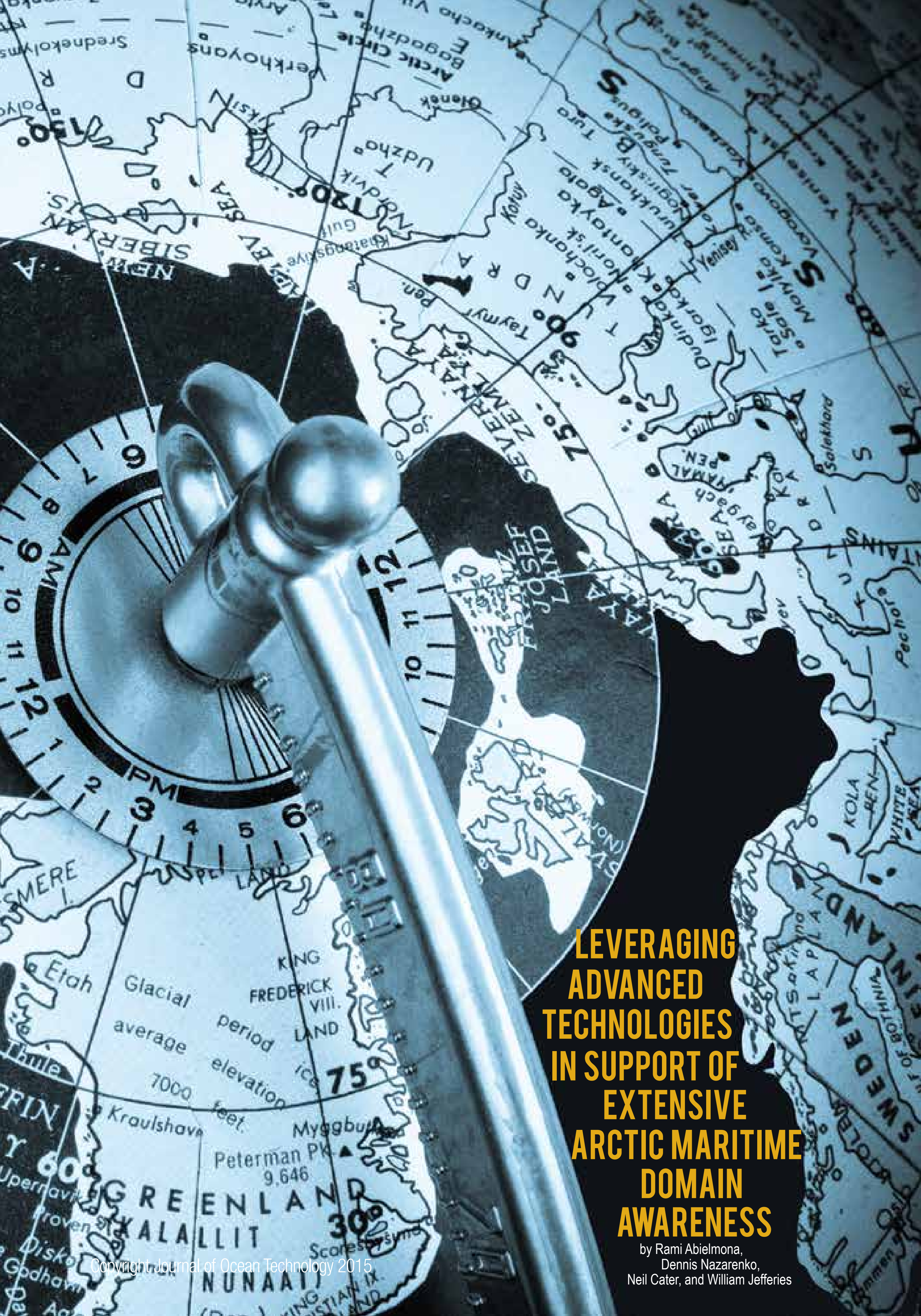


LEVERAGING ADVANCED TECHNOLOGIES IN SUPPORT OF EXTENSIVE ARCTIC MARITIME DOMAIN AWARENESS

by Rami Abielmona, Dennis Nazarenko, Neil Cater, and William Jefferies

The Canadian Arctic has a long and diverse history that mixes the life and culture of aboriginal peoples with those of other groups who have transited the region or stayed, largely on the basis of natural resource driven economic opportunity. With growing interest in the Arctic, the implication is that the volume of marine transportation will increase. This presents needs for improved maritime situational awareness that can benefit a broad group of affected parties. This essay describes a technology-based solution that provides integrated marine information fusion and management capability to address many of these needs. A demonstration in the Greenland, Iceland, and United Kingdom Gap, an important North Atlantic shipping route, serves as an initial evaluation of the capability that is intended for application in the Canadian Arctic.

Introduction

The Canadian north, remote, vast and sparsely populated, has emerged in the early 21st century as a key pillar of Canada's economic growth. The region's concentration of resource potential is unparalleled: whether it is for its mineral, oil and gas, fish, or hydro/power resources, the north is often seen as Canada's great untapped frontier.

Interest in the region's potential is not new; exploration and extraction in the Canadian north dates back to the beginning of the 20th century. What has changed is the scale on which projects are being planned, and the geographic range within which they are envisioned. Accelerated environmental change, increased global demand, and advances in resource extraction technology have redefined the accessibility of northern resources.

Industry is not alone in its interest in the riches of the north. Federal and territorial government bodies and agencies have consistently expressed support for more and better resource development. The dominant requirement of governments is that northern resources be developed sustainably and that benefits be shared equitably among stakeholders. It is expected that resource projects will generate employment and business opportunities, provide a reliable revenue source, and build northern capacity as a way of reducing north-south socio-economic disparities.

Arctic Marine Activity Overview

The Arctic presents many challenges to marine activity because of the harsh climates, sparse population, and limited infrastructure. Under the direction of the Arctic Council, an Arctic Marine Shipping Assessment (AMSA) was conducted with results published in 2009. Results of an extensive survey and consultation process found that almost 6,000 vessels made one or more voyages in the Arctic during the AMSA survey year with most occurring along the coasts of northwest Russia, and in the ice-free waters off Norway, Greenland, Iceland as well as the US Arctic. At the same time, an increasing level of cruise ship activity was noted, frequently by vessels not purpose-built for Arctic waters.

The AMSA report also noted that natural resource development (e.g., hydrocarbons, hard minerals, and fisheries) and regional trade are the key drivers for future Arctic marine activity. The Arctic Council has noted elsewhere that with changing climate conditions and prospects of open water seasons through large parts of the Arctic, vessel traffic can be expected to increase.

With the exception of portions of Russia and Norway, there is a significant lack of infrastructure to support marine activity in the Arctic. By comparison to other ocean regions, the Arctic has significant information gaps in several key areas including hydrographic information along key shipping routes, meteorological and oceanographic data, and sea ice and iceberg information in support of navigational decision-making.

Furthermore, the emergency response capacity necessary to address human or environmental incidents and disasters is limited. As a result, AMSA concluded that large areas of the Arctic have insufficient infrastructure to support safe marine shipping and effectively respond to marine incidents.

A key finding of the AMSA study was that there are few systems to monitor and control the movement of ships in ice-covered Arctic waters as an effective way to reduce the risk of incidents, particularly in areas deemed sensitive for environmental, ecological, or cultural reasons.

Marine Domain Awareness – the Canadian Context

In a world where more than 40% of the population lives within 100 kilometres of a coast and where traditional and asymmetric threats to physical and cyber infrastructures and borders continue to rise each year, countries are becoming increasingly aware of the gaps that exist in their ability to achieve persistent surveillance and continuous awareness of their maritime domains. Persistent surveillance is an essential component in a global system to ensure territorial security. The latter is defined as the prevention, detection, and response to unauthorized persons and/or goods crossing a physical or virtual perimeter, making this problem a security concern of individual, corporate, national, and international scope.

In a vast and sparsely populated country such as Canada, which borders the Atlantic, Pacific, and Arctic oceans, a major aspect of territorial security is the role of maritime domain awareness (MDA) in the identification and assessment of potential threats from maritime approaches to military and interagency responders. MDA is defined as the situational understanding of activities that impact maritime security, safety, economy, or environment. The people, processes, and technological tools that discover, sense, analyze, and react to events and perform physical and virtual defence of the country's borders are the key elements of MDA. The primary objective of MDA is the effective tasking of joint and interagency forces to respond to offensive/illegal activities, disasters and rescue scenarios in the maritime domain.

There are inherent challenges in monitoring, analyzing and acting upon the vast amount of data and information that may be available. In Canada, full domain awareness requires surveillance of 10 million km^2 across the Pacific, Atlantic, and Arctic oceans, over 200 thousand km of coastline, and 5 million km^2 of Arctic landmass.

In recent years, as Canada looks more closely at its maritime safety and security challenge, the north has been the subject of much discussion. As Chair of the Arctic Council in 2013, Canada led the advance of Arctic foreign policy and is still strongly promoting Canadian northern interests. Relevant aspects of the Canadian northern strategy include securing international recognition for the full extent of Canada's continental shelf and addressing Arctic governance and related emerging issues, such as public safety.

Traditionally, maritime transport in Canada's north has been limited in range and proportional to the duration of the operating season due to the harsh operating conditions. Increasing industry activity and changing environmental conditions open the prospect for an increase in activity in this region. For example, a navigable Northwest Passage (NWP) can provide a number of benefits. The NWP is a deeper water channel than the Northern Sea Route and offers a convenient transport route for the oil produced in Alaska and the Mackenzie Delta and for the vast mineral resources of the Canadian north to eastern North American and European markets. A navigable NWP also provides the opportunity for significantly shorter transit times for commercial and non-commercial vessels. A typical voyage between Northern European ports and Asia, transiting via the NWP, is estimated to be approximately 9,180 nautical miles shorter than via Cape Horn or about 3,780 nautical miles shorter than the shipping route through the Panama Canal.

Conservative estimates put typical operating costs for bulk carriers to be in the order of $100 USD per nautical mile, resulting in potential cost savings in the order of $400,000 to $1,000,000 per voyage in this scenario.

The extent to which these advantages are realized through increased trans-Arctic shipping remains to be seen. However, the potential for considerable cost savings dictates further consideration of MDA requirements, particularly given the region's remoteness and limited response infrastructure.

Limitations

At present, there are many loosely connected surveillance systems used to monitor maritime areas resulting in the existing disjointed maritime surveillance architecture. Intra-connected sensors that make up a surveillance system as well as interconnection between systems have been both inflexible and expensive to setup. The interoperability needed to facilitate knowledge sharing between authorized users and systems has typically not been a design consideration.

Additionally, as new monitoring technologies are available and deployed, regulatory authorities risk information overload: operators and analysts overwhelmed by the tide of incoming data, from sensor outputs, databases, reports, and other sources of information. Fortunately in practice, safety and security solutions have, for the most part, been effective particularly where the regions of interest are well delineated, data sources are structured and precise, events-of-interest are sporadic, and response time is not a critical consideration. However, this level of performance is not sustainable over time and on a global scale. To accomplish effective MDA over an area comparable to Canada's areas of responsibilities, any solution proposed to address these challenges will need to feature continuous awareness of the environment unconstrained by data parameters or geographical boundaries; in other words, there must be persistent surveillance.

Information Fusion

In order to accurately and effectively monitor a maritime area, the vast depth and breadth of incoming data must be interpreted and managed. Often referred to as the "big data problem," it is best handled through the creation and maintenance of a real-time representative model of the area of interest. Early solutions attempted to resolve this challenge through low-level information fusion (IF) modules that used complex mathematical formulations or brute force number crunching. However, these solutions have proven to be largely inadequate because the complexity created by the 5-dimensional vector (variety, volume, velocity, variability, and veracity) quickly increased to the point where low-level IF modules were overwhelmed. Low-level IF was only capable of performing fusion when the data itself was limited in volume, involved few types (low variety), did not frequently change in mission-critical applications (low velocity), did not change its meaning often (low variability), and was considered to originate from a trustworthy source (high veracity).

As data volume, type, and complexity continue to exponentially grow, researchers have come to realize that a new approach to the big data problem will eventually be needed. There are tens, if not hundreds, of types of information in textual and natural language context. Data are routinely expressed in terabytes and transactions in millions of transfers per second. Jams and interferences may be expressed in events per second. A new computational paradigm is required.

The Joint Directors of Laboratories defined a data fusion model to tackle the problem of refining a situational picture from a multitude of varying sensors. To address the challenges presented by the big data problem, high-level information fusion (HLIF), which is defined as Fusion Level 2 and above (see Figure 1), has become the focus of recent research and development efforts. HLIF uses a mixture of numeric and symbolic reasoning techniques running in a distributed fashion, over a secure

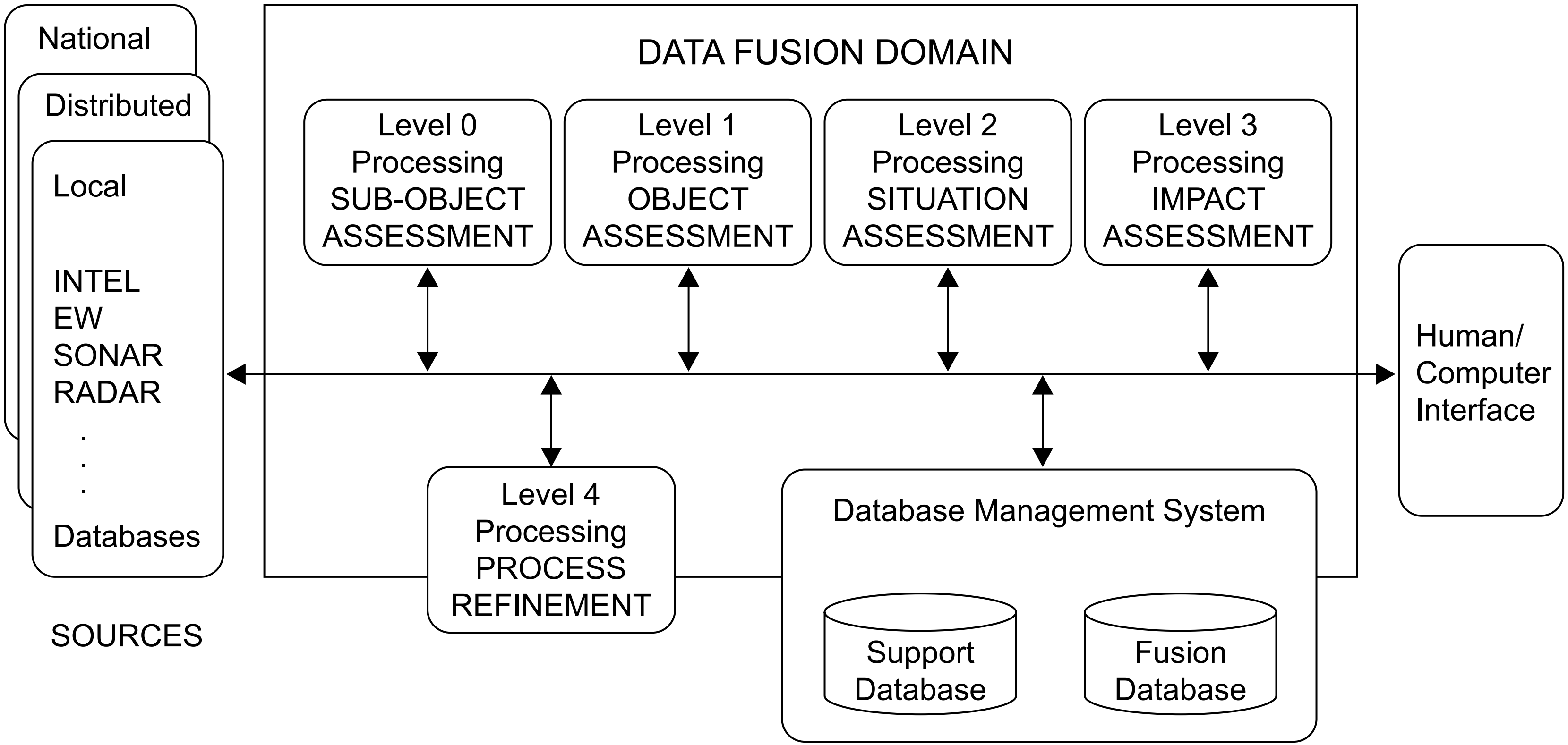


Figure 1: The Joint Directors of Laboratories defined a data fusion model to tackle the problem of refining a situational picture from a multitude of varying sensors.

underlying backbone while disseminating actionable information through an efficient user interface. HLIF allows the system to learn from experience, capture human expertise and guidance, analyze contextually and semantically, lower computational complexity, automatically adapt to changing threats and situations, and display inferential chains and fusion processes graphically.

Instead of attempting to keep up with the ever increasing complexity of the 5-dimensional data streams, HLIF, aided by computational intelligence, allows one to model and, therefore, better understand the data stream sources hence better adapt to the dynamic structures that exist within the data. Thus, the way to create an effective persistent surveillance system is to apply HLIF techniques and algorithms to the problem.

Vessel Behaviour Analysis

Vessel behaviour analysis involves the ingestion of vessel traffic, maritime environment, and other observational reports from various data sources covering an extended maritime area of interest and analyzing the behaviour of reported targets in the context of local conditions.

HLIF based systems that perform behaviour analysis through predictive modelling are capable of dealing with heterogeneous (i.e., multi-source, multi-sensor) data, are mostly automated yet human-centric, and resolve the aforementioned situational awareness issues and challenges. The key is to address four key elements: perception, validation, expectation, and action. The perception module processes and analyses sensor inputs, the latter extracted from data sources, including the environment. Its main function is one of data consumption. The validation module performs the multi-source, multi-sensor data fusion to extract common patterns and parameters from heterogeneous data. Its main function is one of information consumption. The expectation module diffuses commands to actual tasks through predictive modelling. Its main function is one of decision support. Finally, the action module affects the environment by acting out specific tasks. Its main function is one of sensor tasking. An action will change the state of the environment, whence the entire cycle repeats. All the while, a world model represents the knowledge base attained by the system, while the latter is situated and embodied in a real world. Figure 2 depicts the entire flow.

HLIF capabilities are evolving to alleviate the challenges presented by big data including (i) anomaly detection, a process by which patterns are detected in a given dataset that do not conform to a pre-defined typical behaviour (e.g., outliers); (ii) trajectory prediction, a process by which future positions (i.e., states) and motions (i.e., trajectories) of an object are estimated; (iii) intent assessment, a process by which object behaviours are characterized based on their purpose of action; and (iv) threat assessment, a process by which object behaviours are characterized based on the object's capability, opportunity, and intent.

Additionally, real-time adaptive learning becomes an imperative feature of any MDA solution deployed in the field. Situational learning, where future response to already seen situations is shaped based on human feedback, and procedural learning, to minimize the error between predicted and actual events, are two methods that enable a system to better understand its real-world dynamics.

An effective decision support system (DSS) has to intelligently assess regional and worldwide maritime traffic. Current solutions are only effective on a limited basis since most consist of rule-based (i.e., static) and query-based (i.e., reactive) systems that operate on well-delineated regions of interest and structured/precise data sources. A novel DSS uses learning and predictive analytics to perform real-time, automatic detection of abnormal vessel behaviours through the use of computational intelligence to increase operator efficiency while continuously optimizing and improving the operating picture for operators.

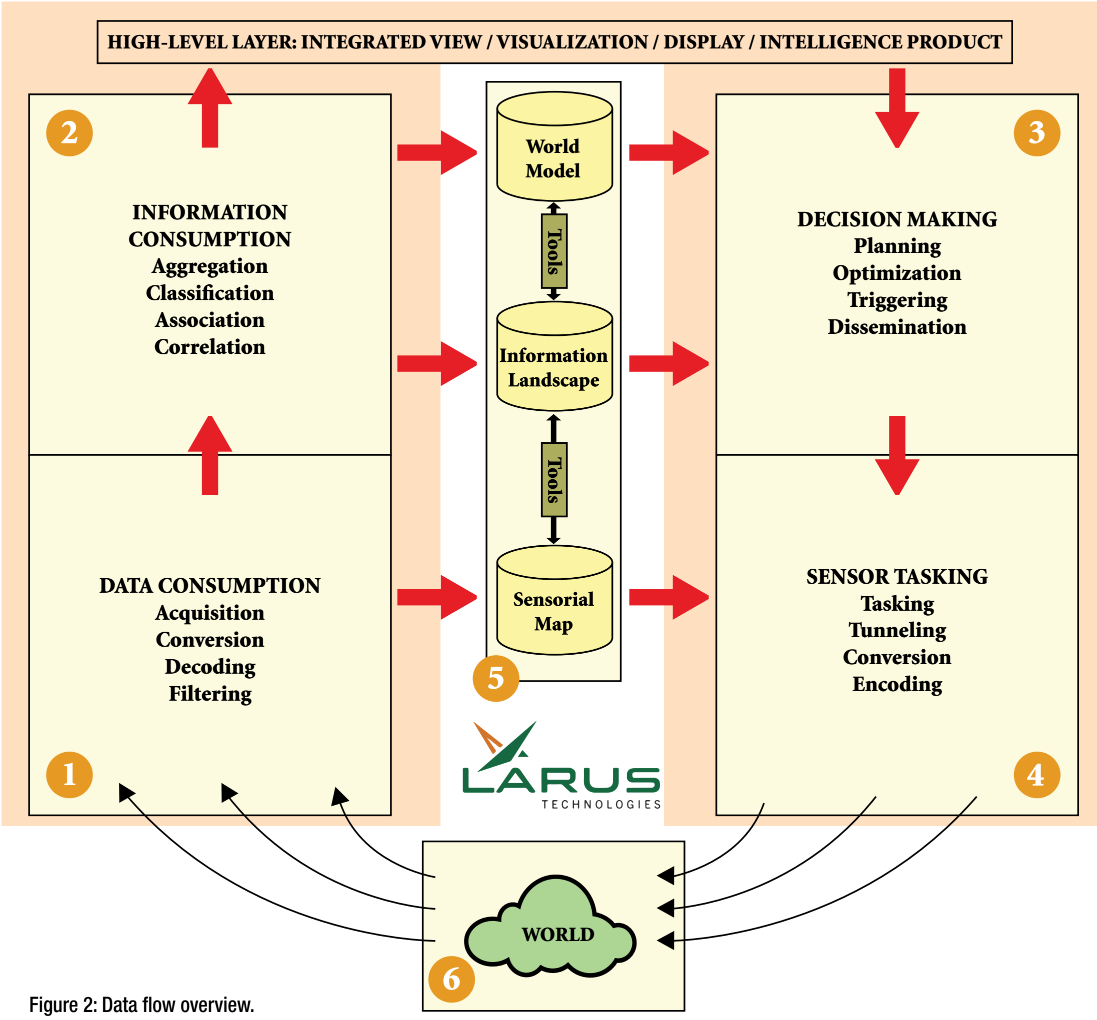


Figure 2: Data flow overview.

Summary and Conclusions

Attention to MDA technologies and systems is growing. Several groups have been identified as potential users of MDA software, including maritime safety and security, maritime transport, fisheries control, marine pollution and environment, customs, border control, general law enforcement, and defence. Investments are being made in research and development as well as procurement and operational implementation. While a key driver for enhanced MDA is increased maritime risks and threats, especially terrorism, piracy, and illegal immigration, each of these user groups share concerns over other marine hazards and issues including safety, economic optimization, and environmental regulatory compliance.

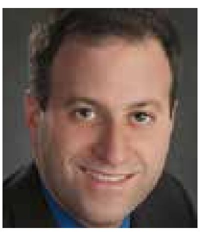
The challenges associated with Arctic marine operations are substantial while the prospects of increased activity in Canada's north strengthen the need for improved awareness and preparedness among a broad base of stakeholders. Advanced technology offers the prospect to develop situational awareness systems that can efficiently integrate and assess data from a broad range of sources.

Acknowledgment

The authors' efforts with respect to situational awareness systems are currently focused in two important areas – predictive assessment of risk and broad based information sharing that we believe are key to successful development of effective situational awareness capabilities

for Canada's north. As part of this effort, Larus Technologies and LOOKNorth have collaborated to demonstrate advanced systems being developed by Larus.

The authors acknowledge the support of exactEarth in providing AIS data in support of the validation project. We also thank our end user partners – the Irish National Space Centre, the Irish Coast Guard, and Kongsberg Satellite Services (KSAT) in Norway for their expertise that is critical to the operational evaluation of both the implementation and benefits of Total::Insight™, the Larus DSS. Finally, LOOKNorth acknowledges the funding support of the Government of Canada through the National Centres of Excellence program, Research and Development Corporation of Newfoundland and Labrador as well as the continuing support of the Government of Newfoundland and Labrador.



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