GENERAL DYNAMICS
Canada

Advanced Robotics for Next-generation Mine Countermeasures

Abstract

Maritime mines are one of the most cost-effective weapons in the naval arsenal. They deny access to coastal zones, thereby seriously impairing the effectiveness of surface and subsurface assets. For this reason, most navies have fleets of mine countermeasures vessels (MCMVs) designed for the six steps of a classic detection, classification, localization, identification, re-acquisition, neutralization (DCLIRN) response. But the challenges of the underwater environment can make a typical MCM mission extremely time-consuming and error-prone. Furthermore, most of the steps require proximity to the mine itself, which is dangerous for the MCMV and its crew. As a result, most navies are turning to underwater robots for DCLRIN missions.

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Introduction

In 1988, the USS Samuel B. Roberts struck an Iranian M-08 mine in the Persian Gulf. The resulting explosion punched a 5-m hole in the hull, knocked the ship's engines from their mounts, and flooded the engine room. The damage cost the United States Navy nearly $100 million.

The M-08 mine was designed in 1908. It costs approximately $1500 to manufacture.

This asymmetry explains why maritime mines are one of the most cost-effective weapons in the naval arsenal. They deny access to coastal zones, thereby seriously impairing the effectiveness of surface and subsurface assets. It is estimated that there are more than 250,000 mines of more than 300 types in the inventories of navies worldwide. These totals do not include underwater improvised explosive devices (UW-IEDs).

For this reason, most navies have fleets of mine countermeasures vessels (MCMVs) designed to detect, classify, and neutralize maritime mines. A typical end-to-end MCM mission can include up to six steps of a classic DCLIRN response:

- Detection: Discover a mine-like object (MLO)
- Classification: Determine whether a MLO is a mine
- Localization: Determine the position of the mine relative to a specific geodetic location
- Identification: Confirm the exact type of mine
- Re-acquisition: Navigate to the identified location
- Neutralization: Render the mine inert

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Robots and Underwater MCM

Several navies currently employ underwater robots in the form of remotely operated vehicles (ROVs) tethered to their mother ships and "flown by wire" by an operator. For example, the Hydra system on the Royal Swedish Navy's Visby class corvettes uses a pair of ROVs (Figure 1). The ROV-Search (left), equipped with a triple-band forward-looking sonar, supports the DCLI portion of the mission, while the ROV-Expendable (right), equipped with a very high frequency imaging sonar and a video camera, is used for re-acquisition and neutralization. The vehicles are controlled through and send data back to the operator via fiber optic cables. They are supported by high frequency hull-mounted sonar (HMS) and a precision acoustic positioning system integrated with the Visby's sonar systems.

Figure 1: ROVs used by the Royal Swedish Navy's Visby class corvettes

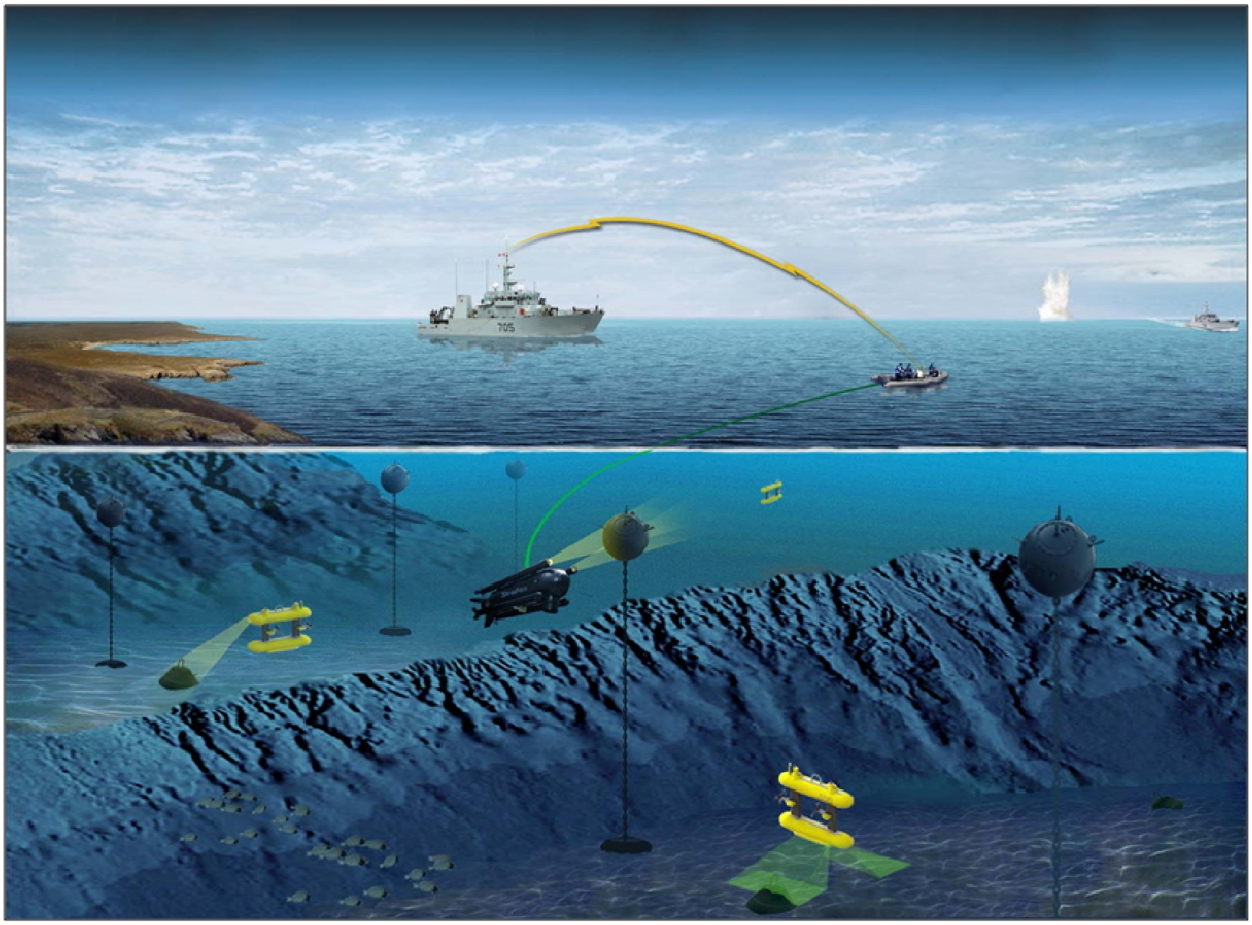
The ROVs allow the Visby and its crew to stand off from a MLO, substantially reducing risk. The Visby class further mitigates that risk by aggressively managing its acoustic and magnetic signatures. This approach was state-of-the-art at the time that the Hydra system was designed. The ROV tethers, however, mean that the ship's stand-off distance is limited to a few hundred meters, which may not be far enough for a traditional steel-hulled ship. The ROV-based solution is also constrained in terms of the number of vehicles that can be practically deployed simultaneously from a single ship, and by the number of people available to operate them.

Seven Requirements for MCM Robotics

The next generation of MCM robotics will use swarms of unmanned, fully autonomous underwater vehicles (AUVs) that travel far from a launch vehicle and operate in a mine field for extended periods of time (Figure 2). This approach promises such a dramatic reduction in risk to ships and sailors that it warrants significant military investment. Furthermore, a single MCMV will be able to launch multiple

AUVs. This will increase operational tempo, reduce manning requirements, and enable general-purpose vessels to be used as MCMVs.

Figure 2: A concept of AUV-based MCM operations



As shown in Figure 2, the MCMV is in radio contact with an RF-to-acoustic communications gateway (in this case a rigid-hulled inflatable boat), which also carries operators that remotely control the disposal vehicle (the SeaFox ROV from Atlas Elektronik). Mine detection, classification, and identification are conducted by a fleet of AUVs (the Marport SQX-500), which communicate with each other and the communication gateway via ad hoc underwater acoustic networking (SeaFire communications suite from Marport and GD Canada).

To enable all six phases of a DCLIRN mission as presented in this illustration, a MCM system that uses swarms of AUVs requires seven separate elements.

High Frequency Hull-mounted Sonars

First, MCMVs or AUV carriers must be equipped with high frequency hull-mounted sonars that provide mine avoidance capabilities. This ensures that the first step in the process — detection — is not overlooked. After all, the best MCM AUV fleet in the world will be of little use if its carrier (or at least its escorts) cannot detect the MLO threat to trigger the MCM mission. The TrailBlazer® Mine and Obstacle Avoidance Sonar (MOAS) derived from the Hydra HMS and jointly developed by General Dynamics Canada and Marport C-Tech Ltd. is an example of leading technology in this area. It provides excellent detection capabilities in shallow-water environments.

Full and Timely Coverage

Second, the AUVs must provide full and timely coverage of an area of interest. This places certain requirements on vehicle speed and endurance. The mission itself places further constraints on maneuverability and stability. The SQX 500 under development by Marport, however, has a unique twin-hull design that enables advanced maneuvering, such as zero-advance rotation, zero-advance crabbing, and hovering in place.

Primary Sensor Payload

The third element required for an advanced MCM system is a primary sensor payload built with very high resolution sonars. For effective DCLIRN, images of the ocean floor and objects of interest must provide sufficient detail to enable identification and classification of mines. This requires range and cross-range resolutions of a few centimeters.

In general, today's MCM sonars operate in a very high frequency band (well over 100 kHz) and use wideband transmission to increase resolution. Many systems use sidescan sonar to provide the highest-resolution available for bottom mapping. But synthetic aperture sonar (SAS) has matured to the point where a number of systems are coming to market. Marport, for example, is developing the AquaPix® interferometric SAS (InSAS) for use on AUVs. This system promises an order of magnitude improvement in resolution for bottom imagery and bathymetry.

High ATR Accuracy

Fourth, true autonomy for an AUV swarm can only be achieved if the AUVs are capable of extracting automatic detections from sonar data. Almost all systems in use today have some form of Automatic Target Recognition (ATR). AUV-based MCM systems require very high ATR accuracy, which enables the AUVs to make decisions without the intervention of an operator. AUVs are also able to quickly acquire views of an MLO from multiple angles, which further increases ATR accuracy.

Sophisticated Communications

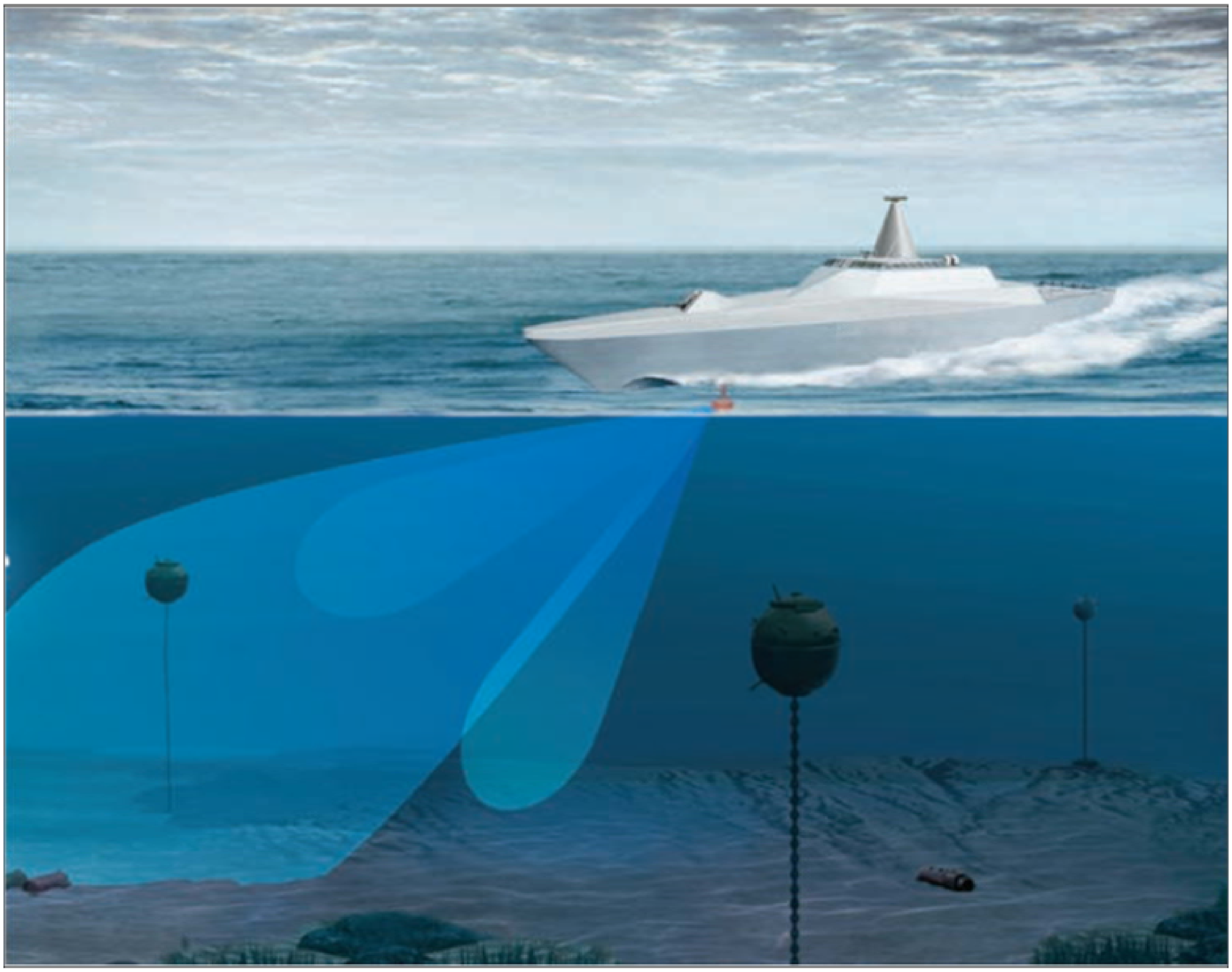
To enable a swarm of AUVs to operate collaboratively, a MCMV also needs sophisticated communications technology. With the right system, effective communications can be established between the MCMV and the AUV fleet. To maximize stand-off distance, this is best achieved with an RF-to-acoustic gateway floating or moored near the minefield. This gateway should also support configuration for direct communication with air- or space-based assets, if required.

Underwater communication is more challenging. Given the variability and unreliability of the underwater communication channel, the network must be capable of adding nodes in an ad hoc and disruption-tolerant fashion. This will allow AUVs to take advantage of any and all communications channels established between vehicles and with the gateway. To create the enabling communications technology for AUV-based MCM, Marport and GD Canada are combining their expertise in underwater communications and disruption-tolerant networking to develop the SeaFire® software-defined acoustic modem.

Accurate Underwater Localization and Navigation

A sixth and related required element is a highly accurate underwater localization and navigation system, which can support precise localization and re-acquisition of identified mines. Traditionally, accurate underwater positioning has combined a surface-based Global Positioning System (GPS) with external acoustic positioning systems and expensive inertial navigation (Figure 3). To reduce per-vehicle cost and size, it is likely that future AUV-based systems will take advantage of new Micro-Electrical Mechanical Systems (MEMS) for inertial navigation, as well as the networked field of collaborating AUVs, to solve the positioning problem.

Figure 3: Traditional underwater mine localization



Mine Neutralization Technology

The last required element in an AUV-based MCM system is a technology for mine neutralization. As previously noted, ROVs specifically designed for mine disposal are already on the market. Other systems use helicopter-based weapons, divers, or specialized surface ships to neutralize various types of mines. It is likely that AUVs will also take a role in this part of the MCM mission, although most navies will keep multiple tools in their arsenal.

Conclusion

Of course, these seven elements do not make an MCM solution by themselves. The biggest challenge is to integrate these disparate and evolving technologies into an efficient system. With proper integration an AUV-based MCM solution can reduce the time and eliminate the errors associated with MCM missions. Ultimately, this will improve the safety and effectiveness of naval assets.

Acronyms

Term	Definition
ATR	Automatic Target Recognition
AUV	Autonomous Underwater Vehicle
DCLIRN	Detection, Classification, Localization, Identification, Re-Acquisition, Neutralization
GPS	Global Positioning System
HMS	Hull-Mounted Sonar
InSAS	Interferometric SAS
MCMV	Mine Countermeasures Vessel
MEMS	Micro-Electrical Mechanical Systems
MLO	Mine-Like Object
MOAS	Mine and Obstacle Avoidance Sonar
ROV	Remotely Operated Vehicle
SAS	Synthetic Aperture Sonar
UW-IED	Underwater Improvised Explosive Device

References

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