UxV National Security MAD CONOPS

Using Magnetic Anomaly Detection for National Security CONOPS

Background

Recent advances in CAE's magnetic anomaly detection (MAD) sensors and processing technologies present novel opportunities that hold potential for contributionsto the domains of defence and security, and the environment.

For decades military maritime aircraft have used MAD sensors as contributing sensors in Anti-Submarine Warfare (ASW) to detect and track military submarines that posed national security risks. During the Cold War, this game of hide-and-seek was continuous, and nations expended significant resources to improve their sensors and system technologies. Specific driving forces included the reduction in target (submarine) magnetic signatures and the desire to place MAD sensors on smaller platforms such as maritime helicopters, and uncrewed platforms.

Today, the leaps in remote access and autonomous technologies combined with ever-decreasing platform size, have ushered in new opportunities to employ MAD technology. These advances have provided the stimulus to improve the sensitivity, size, weight, and power consumption of MAD technology itself. Combined, these activities have opened the doors to several exciting opportunities.

The Challenge

Moving forward with MAD technology presents an opportunity to expand a proven technology in environments and domains that present demanding yet surmountable technical and operational challenges. One significant improvement is the deployment of the sensor on alternate platforms. The advances in autonomous and remotely deployed platforms such as Uncrewed Aerial Vehicles (UAV), Uncrewed Surface Vessels (USV) and Uncrewed Underwater Vehicles (UUV) (collectively referred to as UxV) allow for additional potential deployments. The detection of magnetic anomalies is affected by the distance between the sensor and the target, therefore mounting the sensor on UxVs offers the possibility of increased detection capabilities by reducing the distance between the sensor and target.

Additional investment in newer technologies can further reduce the footprint of the MAD Sensor device. In addition, the software can be evolved to improve detection capabilities and expand deployment configurations. This combined software and hardware is referred to as the MAD System.

Proposed Concepts of Operation

National Security CONOPS

There are several Concepts of Operations (CONOP)s related to National Security that make use of magnetometers.

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Cable Monitoring and Protection

Underwater cables are high value target and require monitoring and maintenance. When problems occur with the cables, they can generate unwanted modulation, or harmonics that indicate the wave is distorted. These signals occur in the Extremely Low Frequency (ELF) range. A MAD sensor with ELF signal processing could be used to scan power cables to identify these types of problems. Magnetometers are currently being used to image buried cables that are part of underwater infrastructure to verify their integrity [3]. MAD could also be used to detect signal boosters on fiberoptic cables.

Incorporating a UxV with MAD systems into Subsea Seabed Warfare (SSW) CONOPS could be beneficial for cable protection.

Search and Rescue

In SAR activities, time management is a critical element to achieve success. Fast deployment of search capabilities and precise localization of the target is key to success. MAD sensors, mounted on UxV, can reach search zones rapidly and search shallow waters as well as deep water, provided the target is within sensor range. Use of UUV platforms can also increase the maximum detection depths of the sensor compared to an airborne platform.

Oil/Mineral Exploration and Geo-mapping, Scanning before digging

Oil and mineral exploration are frequently conducted in deep waters [3]. Due to the inverse cube relationship between the strength of a detection and the distance between sensor and target, MAD sensors are currently used in littoral (shallow) regions. Mounting a MAD sensor on a UUV could allow the sensor to explore the deeper waters where such exploration takes place.

In addition to scanning for deposits of interest, geo-mapping of the ocean floor could be done by combining bathymetric and MAD sensor data. The UUV would require software with autonomous function to navigate areas where mapping is taking place.

Scientific Research & Exploration

The current signal processing algorithms of the MAD System are the result of over forty years of real-world deployment. Moving forward, collaboration between CAE and scientific expertise within research institutions may identify additional methods of system deployment.

Safety Enforcement / Environmental Monitoring

Mine tailings containing heavy metals are sometimes disposed of by dumping them into the ocean, or are carried down a river from a mine, and deposited into an estuary at the river and ocean interface. The MAD Sensor could be used to search for large deposits of heavy metals resulting from such operations.

Marine Archeology

Marine Archaeology currently uses surface-towed or near-bottom magnetometers. Both are towed approximately two ship lengths away from the ship to allow data collection while reducing interference from the towing ship's magnetic field. The sensors are used to map the geology of wreck sites and determine the composition of magnetic materials found on the sea floor. In 2001, a magnetometer was used to identify components of Roman concrete.

Search & Salvage Operations

While Marine Archaeology often focusses on pre-iron-age shipwrecks, salvage operations may be more interested in locating modern ships [3]. The same deployment of the sensor could be used for both.

Military CONOPS

Current CONOPs for ASW involve mounting a MAD sensor on a vehicle and flying low over the water surface. However, the evolution of UUV has increased subsea threats, which requires new identification or detection techniques. The CONOPS in this section describe possible ways to evolve the use of a MAD sensor for ASW or SSW.

Magnetic Buoys

Similar to sonobuoys, magnetic buoys could be deployed on an as-needed basis.. This idea is not new, but a MAD sensor combined with advanced signal processing techniques could improve the concept, taking advantage of a sensor with a large dynamic range and frequency coverage. A smaller, cheaper sensor could be used with existing MAD algorithms. Otherwise, CONOPs must include the recovery of the magnetic buoys, since a traditional expendable approach may be cost prohibitive in some methods of employment.

Fixed Underwater Arrays

In some locations, rather than mounting a MAD sensor on a moving platform, sensors could be mounted to a fixed underwater structure and detect targets moving past. Identified targets and potential threats would be reported back to a Command and Control center. If the sensor is integrated with a library of known targets, the report could include initial classification using automatic target recognition (ATR) algorithms and provide characteristics of the detected object. A fixed sensor employment could monitor a harbor, bay, or river entrances, and when combined with other ASW and SSW systems, improve protection effectivess against threats. Usage of underwater MAD sensors for monitoring is comparable to acoustic sonobuoys. A single sensor can provide valuable position and classification information. To further enhance the capability, a network of fixed sensors can be installed in a linear, planar, or volumetric array configuration to maximize coverage to the specific bathymetry of deployment. Further investigation is needed to optimize a networked employment.

Degaussing Facilities

Degaussing is the process of reducing or removing naturally occurring magnetic fields surrounding metal ships and reduces the target strength detected by magnetic proximity fuses naval mines. Degaussing can be achieved with permanently installed shipboard equipment or at external facilities, that change the bias field, based on measurements performed on a magnetic signature sensing range [2]. MAD sensors are routinely used to measure a vessel's magnetic signature to evaluate degaussing activities and identify future degaussing requirements. MAD sensors are used in the calibration process by providing magnetic data from the ship, both from underwater measurement (on a UUV or on a moored sensor), or on an airborne platform such as a drone. This is useful to tackle one of the main challenges of calibration, which is to discriminate between induced and permanent vertical components of the ship signature.

Intelligence, Surveillance & Reconnaissance (ISR)

ISR operations with MAD sensors could include indicating whether mine stockpiles have been accessed, mines have been moved, or mine-laying operations have been conducted [3].

If a UxV detects a moving suspicious object, the vehicle could be tasked to follow the target and report back its position.

Magnetic Surveys of Areas of Interest

A MAD sensor mounted on a UxV could be used to perform a magnetic survey in a littoral area of interest for which there is no current magnetic geomagnetic database, to develop a baseline magnetic survey. This geomagnetic database could then be used to determine whether a detection is valid or known magnetic characteristics of the area.

Mine Detection and Countermeasures

In the Land and maritime domains, mine Countermeasure Missions are meant to establish safe operating areas and transit routes and lanes [3]. These missions may be open or clandestine. Such missions include reconnaissance, clearance, mechanical and influence sweeping, and protection.

A MAD sensor mounted on a UxV, or a crewed helicopter or vessel, could be used in the reconnaissance phase, which includes detection, classification, identification and localization. Adding a library of known mine signatures could aid in the identification phase. In a study conducted by the US Navy long-range detection sensors were found to have little value, while classification/identification sensors were determined to be a viable sensor combination [3].

Mines that are completely buried in sandy ocean sediments are considered to be undetectable by sonars operating at higher frequencies on the order of hundreds of kHz[3]. Magnetic detection could be a better option in this case for buried metal mines.

Proposed Deployment Challenges

Platform Considerations

This section discusses the various challenges and considerations that must be addressed to transition from an airborne environment to a marine platform.

Water Resistance

From a hardware point of view, the most important challenge is perceived to be the adaptation of existing MAD sensors and associated capsule/mounting means, to a platform potentially exposed to seawater and sea pressure. This includes the sensor itself as well as the cables/connectors.

There are several ways to attack this challenge. The first step is to identify requirements, target dependent, and can be very different between a proof-of-concept deployment and the final integration.

For example, in a concept system, the sensor may be placed on a towed barge where it would be exposed to seawater and mist, rather than on the final vehicle installation, which could be waterproof.

In general, the aim of any such investigation would be to make minimal modifications to the sensor. Ideally, any water resistance or waterproofing would be achieved through the capsule in which the sensor is placed.

Noise from Platforms

The MAD Processing Software compensates for the magnetic noise from airborne platforms. UUVs and USVs would also generate noise, but the noise depends on the type of platform. Investigation would be required to identify how to modify the signal processing software to account for the noise of the platform. In particular, noise induced by the platform moving with the water mass is something that requires further study.

On-Board Processing

A MAD sensor with signal processing capability would require a computer for running the accompanying software. Some UUVs/USVs come with on-board computers that could be used to perform processing. Alternately, a waterproof processor could be sourced to install with the sensor.

Solution Characteristics

The solution to the challenge has a strong foothold in the current state of the MAD Extended Role (XR) system.

The MAD System

Over the last decade, the MAD sensor from CAE has undergone a modernization program to reduce its physical footprint, and to modernize its signal processing capabilities. The result is the Magnetic Anomaly Detector Extended Role (MAD-XR) System. The new system is more adaptable than its predecessors and lends itself to being adapted for new CONOPS. In particular, there may be advantages to deploying the MAD System on UxVs.

The MAD-XR System is made up of a number of components, as can be seen in the following diagram.

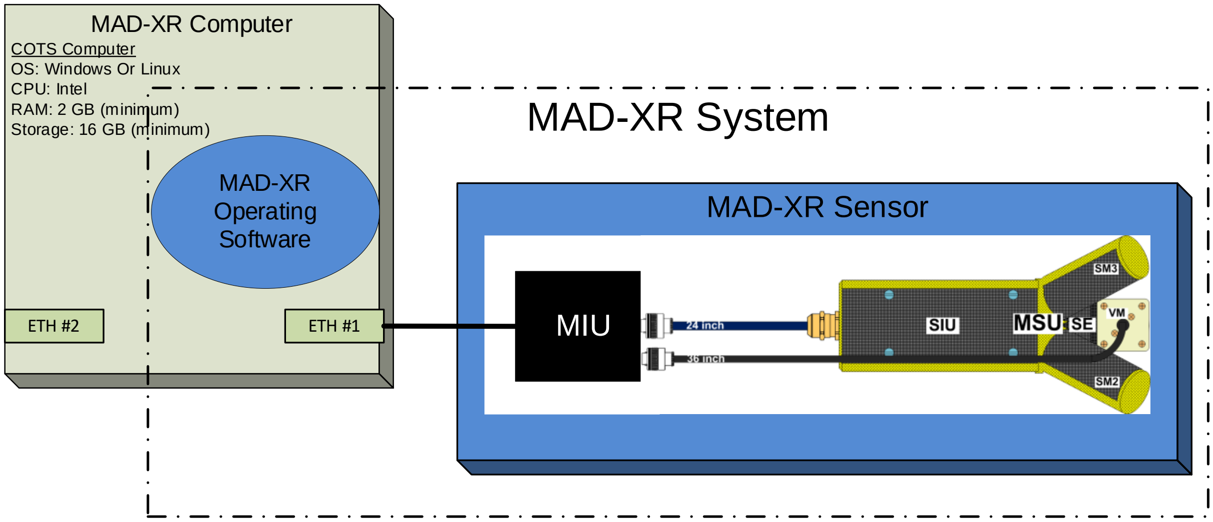

Figure 1 MAD-XR System

- The Magnetometer Sensor Unit (MSU) is the physical sensor with three Scalar Magnetometers (SM) and a Vector Magnetometer (VM).
- The MAD-XR Sensor is the MSU plus the Magnetometer Interface Unit (MIU), a processor that generates formatted output on an Ethernet interface.
- The MAD-XR System is the MAD-XR Sensor plus the Operational Software (OpSW) that performs signal processing and identifies potential targets. The OpSW runs on a computer that is often provided by the customer. It communicates with the MAD-XR Sensor via an Ethernet port and it outputs formatted messages on another Ethernet port. It has a modular design, so processing can be divided between multiple processors depending on the overall system architecture.

Potential Capability Enhancements

Even though the MAD-XR sensor was designed for several roles, several adaptations would be required to enter the UUV and USV market, mostly on the software side. Others will likely be identified as use cases for the system are developed. Note that not all enhancements need to be developed before a proof-of-concept system is implemented, but the MAD roadmap should plan for them.

Accelerometer for compensating for wave noise

The MAD-XR Sensor MIU includes a 3-axis accelerometer device, which can compensate for noise due to rapid displacement of the sensor within the ambient field. An example of this kind of displacement would be noise induced by the proximity of the sea surface waves, if the sensor operates at very low altitude (airborne), or on a USV or UUV close to the surface. CAE is well versed in compensation techniques based on external inputs, such as flight controls, vector magnetometers, etc..

A GPS can provide useful data to supplement the accelerometers for this algorithm. Inertial navigation data and other values provided by the sensors that come bundled with the platform could also be used by the signal processing algorithms. Note that navigation data is already used by the MAD-XR operational software.

Integrating data from other platform-mounted sensors

Uncrewed vehicles come equipped with a variety of built-in sensors, in addition to the user-added payload. These sensors provide information about the environment such as High Definition (HD) Machine Vision, temperature, salinity, pressure and bathymetry[1]. A possible enhancement to the MAD software would be to use real-time sensor data in addition to the stored maps used for geomagnetic compensation. Conversely, the MAD-XR System could provide magnetic data to augment the bathymetric data presented to the operator.

In addition, the MAD-XR System could be used in combination with sonars to present a more complete environmental picture. The MAD-XR Sensor can expand the range of data collected by a sonar array with its ELF capability.

Working with a geomagnetic database of the area of interest would allow the MAD-XR algorithm to discriminate between the detection of natural features and detections that may indicate targets of interest.

Integrating signal processing with additional library types

Work is underway to adapt the MAD sensor software interface with geomagnetic databases to predict magnetic measurements of known features of an area. Additional algorithms should be investigated that would allow the software to work with databases containing libraries of possible target types, such as mines. In cases where the target has a dynamic, time varying signature, such as a generator or a power/telecommunication cable, it may generate signals in the ELF range. The MAD-XR Sensor can detect ELF signatures, and could make use of a library of known ELF signatures.

Tuning of algorithm to work with smaller detections

The current MAD-XR software is optimized to detect large objects such as submarines. Testing and tuning will be required to adapt the existing algorithms to different platforms, targets and environments. The current airborne usage of the MAD-XR System relies on years of collected data on many types of airborne platforms, as well as proven simulation models for target signatures, platform noise, and environmental noise. In the case of UUV and USV, CAE will need to acquire more detailed knowledge of the problem space, through data collection and collaboration with organizations willing to share data.

Smart Sonobuoys

Sonobuoys can be deployed to create an underwater virtual fence, either by putting them in fixed locations, or dropping them to surround a target of interest. If MAD algorithms can be adapted to work with smaller, more affordable sensors, then they could be deployed on UxVs and the sensors could be deployed in similar ways to sonobuoys, including creating an underwater virtual fence.

MAD-XR Discriminators

The existing MAD System already has a number of key discriminators that uniquely position it in the marketplace. These features could be leveraged in many proposed new deployments.

Extremely Low Frequency (ELF)

The MAD-XR Sensor is capable of detecting ELF signals outside of the range currently reported by fielded MAD-XR Systems. The OpSW could be updated to identify targets in the ELF range. This could broaden the possible uses of the system, including Cable Scanning.

Continuous Compensation

Continuous compensation is a feature that has been a key discriminator for CAE's MAD technology since the 1980s. It is a unique processing technique which eliminates the need for periodic aircraft magnetic interference adjustments. It provides optimum maneuver-related compensation at all times, at all latitudes, and with any combination of weapon and stores load. Immediately upon initiation of continuous compensation, the process begins to correct for any magnetic source variations on the aircraft while in flight. This process can be readily adapted to other types of platforms such as USVs or UUVs once their noise profiles have been identified.

No Dead Zones

The MAD-XR sensor uses three scalar magnetometers, each mounted at 45 degrees with respect to the plane formed by the two others. This design, combined with digital switching between magnetometers, ensures that there are no dead zones in any orientation of the sensor, while maintaining excellent resistance to magnetic gradients. In the context of a USV or a UUV, which are likely to have smaller maneuver angular envelopes than an aircraft, it may be possible to reduce the number of scalar magnetometers, and use mechanical adjustments to compensate. This option would require a re-design of the MSU, and would be considered once proof of concept on an aquatic platform has been established.

Militarized

The MAD-XR sensor is a modern form factor of a proven sensor that has been deployed with multiple military organizations over the past 40 years. The hardware meets several military standards, including MIL-STD-810G, and MIL-STD-461F. A lengthy phase of development was required to attain this level of hardware maturity, which provides a definite schedule and risk advantage to the MAD-XR, compared to other sensors which are still in the prototype stage, or currently used in laboratory environments only.

The hardware and software are developed using a Quality Management System that conforms to AS9100 for the overall product and AS9115 for the software.

Other Advantages

The MAD-XR sensor's detection capability is passive – it reads the magnetic field in the environment around it. As a result, while the platform can be detected, the scanning function of the sensor cannot be detected when it is operating. Traditional countermeasures such as jamming the sensor would imply surpassing the earth magnetic field to prevent accurate detection. At this time, the technical difficulties creating such a large magnetic field makes jamming the sensor improbable. The MAD-XR is also impervious to typical weaknesses of sonar-based sensors, such as echoes.

Recommendations

Prototyping an Aquatic MAD deployment

CAE sees high potential for significant additional value from pursuing application of the MAD-XR system to UxV platforms. As such, we actively seek partnerships with research organizations and customers to drive a proof of concept activity in the near term, followed by growth and maturity of the technology towards operational readiness.

Recommended steps to produce a Proof-Of-Concept system:

- Identify a CONOP for the proof of concept system. This should be a scenario that can be reasonably implemented as a first pass. Part of this effort will require defining and capturing potential CONOP requirements to evaluate the one that is the most feasible.
- Identify the requirements to deploy the MAD-XR System to operate in an aquatic environment. This could include identifying work required to produce/procure a waterproof housing for the system.
- Design the prototype system.
- Build the prototype system.
- Evaluate the prototype system.
- Write up recommendations for next step.

Post Prototype Activities

Details for the next steps after the prototype has been implemented will depend on the recommendations from the prototype evaluation. This could include any of the following activities:

- Capture requirements for a potential platforms based on the CONOP, including Small UAS.
- Capture communication requirements for a multiple sensor solution.
- Identify a manufacturer willing to team with CAE. Some companies with nearby underwater testing facilities[1] have already opened channels.
- Identify requirements for what is needed to deploy MAD-XR for other uses, such as for degaussing.

[1] For example, CAE has witnessed in the past third-party sonar testing at the NUWC Seneca Lake Test Facility https://www.navsea.navy.mil/Home/Warfare-Centers/NUWC-Newport/What-We-Do/Detachments/Seneca-Lake/ .

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