CMRE UXO TEST SITE IMPLEMENTATION, DEMONSTRATION AND MAINTENANCE

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Abstract: *The problem of underwater UneXploded Ordnance (UXO) remediation is, if possible, long and complex using conventional methods such as divers in the field. The last decade has seen a proliferation of autonomous underwater and surface systems, dedicated or adapted to the purpose. Performance evaluation of these systems requires at sea testing in well-defined and controlled conditions, to be recreated and documented as executing a Project aiming to implement, maintain and operate an underwater UXO test site in the gulf of La accurately as possible. The NATO-STO-CMRE, under the sponsorship of the ESTCP, is Spezia, Italy, providing logistic and technical support to external Demonstrators, and disseminating results through ESTCP-SERDP initiatives, workshops and conferences. First demonstrations are planned for September 2023.*

Keywords: *munitions remediation, UXO testbeds, UXO detection and classification*

1. INTRODUCTION

The issues related to the presence of UXOs in maritime areas is increasingly affecting the environmental protection communities, in Europe and the USA, with several hundreds of underwater sites that are potentially contaminated with munitions from military activities; many of these sites are in shallow water depth, close to the shoreline, and the unexploded munitions can pose a real threat to the human health and the environment.

The Strategic Environmental Research and Development Program (SERDP) and the ESTCP are the USA DOD research programs, harnessing the latest science and technology to improve performance, reduce costs, and enhance and sustain mission capabilities in the environmental protection and restoration. One of the SERDP-ESTCP programs areas (https://serdp-estcp.org/Program-Areas), namely the Munitions Response (MR) program, has recently moved its support to the remediation of underwater UXO found in ponds, lakes, rivers, estuaries, and coastal, shallow areas (water depths up to 30 meters).

The initial phase of such process involves the investigation of innovative technologies that can detect, characterize, and classify UXOs: autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), towed systems, surface systems, crawlers, and airborne platforms, equipped with suites of optical, acoustic, active and passive electromagnetic and magnetic sensor, able to detect proud or buried targets.

The evaluation of these equipment, in terms of autonomy, automation and performance, should be carried out at suitably selected demonstration sites (Testbeds), in controlled environmental conditions, against the wider range of targets (UXOs and clutter, purposely deployed and accurately geolocated) and with a strictly quantitative scoring process developed and implemented by an independent Authority (USA Institute for Defence Analyses (IDA) for SERDP-ESTCP demonstrations).

Early 2021, the US Environmental Security Technology Certification Program (ESTCP, the US Department of Defense (DOD) environmental technology demonstration and validation program) awarded CMRE a grant for a project to implement, maintain, manage and monitor a UXO Testbed site, located at CMRE facilities, in the harbour of La Spezia, Italy.

Activities under this Project include the collection of the relevant authorizations from the local Authorities, the environmental characterization of the site, the seeding of the area with selected inert ordnance and manmade clutter objects, and a final survey to determine the ground truth, prior to any system testing demonstrations. Two demonstration periods are planned for 2023 and 2024, each one followed by a technical workshop to disseminate the results to the relevant scientific and technical communities, and review lessons learned.

2. STANDARDIZED UXO TESTBEDS

The development of standardized underwater UXO Testbeds was the objective of a dedicated workshop held during the SERDP and ESTCP 2018 Symposium (https://serdp-estcp.org/News-and-Events/Conferences-Workshops/Past-MR-Workshops/Underwater-UXOTest-Bed-Workshop-Nov-2018). The workshop followed a systematic approach to establish the requirements, frameworks, protocols, responsibilities and timelines to be adopted during the development of UXO Testbeds [1].

Multiple underwater testbeds (Table 1) are currently being proposed, developed or operated by US and European Institutions under the sponsorship of SERDP/ESTCP, in agreement with the guidelines and recommendations emerged during the workshop, to form a network of sites used to evaluate and demonstrate the UXO detection and classification technologies proposed by Industries, Research Centres, and other Agencies.

Site	Location	Organization	POC
Sequim Bay Demonstration Site	Sequim, WA, USA	PNNL	Dana Woodruff, dana.woodruff@pnnl.gov
Shell Island, NE Gulf of Mexico	Panama City, FL, USA	NSWC-PCD	Ray Lim, raymond.lim@navy.mil
Hawai‘i Munitions Test Range Complex	Honolulu, HI, USA	ARL University of Hawaii	Margo Edwards, margo@arl.hawaii.edu
Digital Ocean Laboratory	Rostock, Germany	Fraunhofer IGD – Ocean Technology Campus Rostock	Peter Menzel, peter.menzel@igd-r.fraunhofer.de

CMRE UXO Testbed	La Spezia, Italy	NATO-STO-CMRE	Stefano Biagini, Per Arne Sletner, stefano.biagini@cmre.nato.int perarne.sletner@cmre.nato.int

Table 1 – Underwater UXO Testbed currently under development under SERDP/ESTCP sponsorship

3. THE CMRE TESTBED SITE

The site selected for the implementation of the UXO Testbed is a water basin adjacent to the CMRE facilities in the harbour of La Spezia, Italy. (See Figure 1), Being included in a Military compound, the area is constantly under surveillance, with anchoring and fishing interdicted, and cleared to perform surface and underwater tests of vehicles and sensors, as well as professional diving activities.

The Testbed Area extends on a rectangle of about 540m x 220m, with depth ranging from 5m to 12m and a prevalent mud/silt bottom sediment. The gulf of La Spezia offers the Testbed a mild climate, and protection from winds and waves, with limited currents and negligible tides.

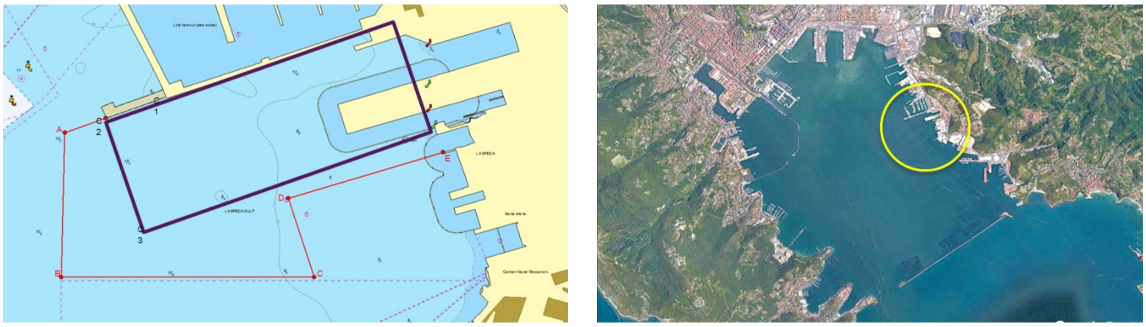

Figure 1 – The CMRE UXO Testbed site in the harbour of La Spezia

The presence of CMRE facilities offers the Managers and the Users of the Testbed the availability of a full range of engineering and logistic support services (electromechanical and electronic workshops, calibration laboratories, office spaces, conference rooms, piers, cranes, workboats).

4. PLANNING AND IMPLEMENTATION

Authorization – Scientific, technological and engineering trials in the CMRE basin are authorized in the framework of the Memorandum of Understanding (MoU, 2017) with the Italian Navy “Centro Di Supporto Sperimentazione Navale (CSSN, Naval Support and Experimentation Centre, managing the Compound where CMRE facilities are located). Special authorizations to perform sediment sampling, emplace the UXO and clutter objects, and grant Demonstrators access to the Compound have been included in a dedicated Technical Agreement (March 2021).

Environmental characterization - The first step of the Testbed implementation phase has been a full environmental characterization of the site, through a suite of sensors and equipment installed on surface and underwater vehicles, or permanently deployed in the area for other CMRE research projects.

The measurements and data collections, spanning for a time interval of about six months in the second half of 2021, are summarized in Table 2. All environmental data will be provided to Demonstrators during the trials, in a suitably accessible data catalogue.

Product	**Sampling Period**	**Method**
Bathymetry	N/A	Multibeam Echosounder on AUV
	N/A	Multibeam Echosounder on Ship
Backscattering	N/A	Blueview MBES on AUV & EM3002 (TBC)
Sediment		Grab Samples from RHIB
	N/A	Sub-bottom Profiler survey from Workboat
Bottom Type	N/A	Historical data set
Salinity	1 d	CTD manually deployed from RHIB
Water Temperature	1 d	CTD manually deployed from RHIB
	5 s	Thermistor chain, 10 sensors, 1m depth spacing, moored
	15 s	Public Meteo/Marine Station in close vicinity (ISPRA-06)
Sound speed	60 s	2xSVPs, bottom deployed
Turbidity	1 d	CTD w/turbidity sensor, manually deployed from RHIB
Current	1 s	ADCP with Waves module, bottom deployed
Waves	1 s	ADCP with Waves module, bottom deployed
Tides	1 h	Public Meteo/Marine Station in close vicinity (ISPRA-06)
Air Temp	15 s	Every 15 s
Humidity	60 s	CMRE Meteo Station
	15 s	Public Meteo/Marine Station in close vicinity (ISPRA-06)
Wind	60 s	CMRE Meteo Station
	15 s	Public Meteo/Marine Station in close vicinity (ISPRA-06)
Barometric Pressure	60 s	CMRE Meteo Station
	15 s	Public Meteo/Marine Station in close vicinity (ISPRA-06)
Total Rainfall	60 s	CMRE Meteo Station

Table 2 – Environmental characterization measurements at the CMRE UXO Testbed

Targets Selection - A number of dummy and replica UXO targets has been procured through local military institutions, namely the Italian Navy "Balipedio Cottrau (experimental naval artillery shooting range in La Spezia) and the "Stabilimento Militare Ripristini e Recuperi del Munizionamento, Agenzia Industrie Difesa" (military establishment for the disposal of ammunitions and explosives in Noceto, Parma). The UXO targets have been selected to form a representative sample of NATO naval and terrestrial artillery ammunitions.

Additional clutter (commonly found objects in a harbour environment, like cement and metal parts, anchors, fishing equipment) has been added to the targets catalogue. The best effort has been made to procure a significant number of objects to be deployed, to increase the effectiveness of the scoring process during the demonstrations [2], [3].

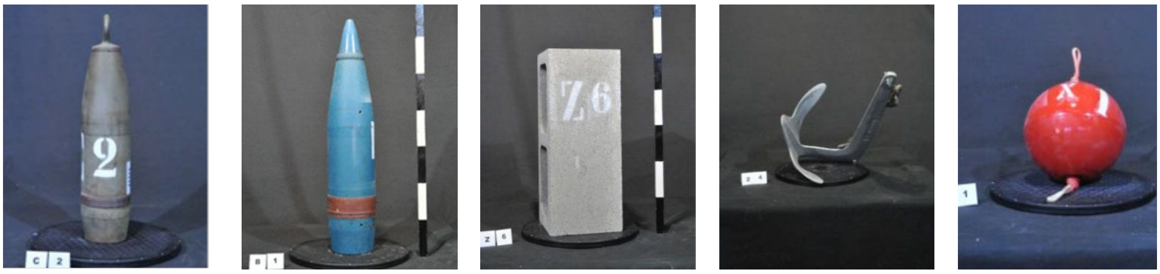

Figure 2 – Examples of UXO and clutter deployed at the CMRE UXO Testbed

The inert UXOs have been filled with suitable compound, with the primary purpose to match the weight in air (density) of the corresponding live ammunitions. However, other filler characteristics (sound speed, acoustic impedance) will be considered, to determine a realistic response of the UXO to low frequency acoustic detection and classification systems. Inventories of UXO characteristics (from drawings to mechanical, acoustic and magnetic numerical analysis) have been made available in the framework of other SERDP-ESTCP MR Projects.

To prevent the Demonstrators from gaining possible visual clues, the aspect of the Targets has been maintained as much as possible close to the original (shape, colour, layout), avoiding the use of additional mooring gears (eyebolts, shackles) in favour of direct splicing to the thin ropes (2mm dia.) used for deployment.

Targets Deployment - Two separate areas have been defined within the Testbed site: a Calibration Area (or Instrument Validation Strip, IVS), where samples of all object types are deployed along a line, and positions of each target is provided to Demonstrators, for systems training, testing and validation; and a Blind Area, where targets are disposed on a random pattern within a circular perimeter (R=100m), and all deployment details are undisclosed to Demonstrators, to achieve the most reliable evaluation (quantitative scoring) of detection and classification capabilities of the proposed systems.

Figure 3 – Deployment of UXO and clutter at the CMRE UXO Testbed

The number, type and position of UXOs and additional clutter have been planned and approved in agreement with ESTCP and IDA Program Officers. The horizontal separation between objects has been kept equal or larger than 10m, safely larger than expected sensors resolution and typical detection halos adopted during the scoring process [2].

Targets were clean at deployment, and none of them has been deliberately buried into the sediment; burial and fouling will happen naturally and will be monitored through divers inspection every about two months. If required by Demonstrators, deep burial of some of the targets (up to 0.5m depth) could be performed manually by divers.

Deployment of targets has been performed from a RHIB, equipped with a light, hand operated crane (see Figure 3).

5. TARGETS GEOPOSITIONING

An accurate and measurable geopositioning of the UXO and additional targets is fundamental for the evaluation of the detection systems proposed by Demonstrators. The true information (ground truth) about the objects, actually present in the Testbed area should necessarily include type and geographical position (conventionally the flat-plane N and E coordinates in UTM units), as well as other secondary information (e.g. burial depth, orientation and attitude, and other characteristics (corrosion, biofouling).

The detection performance of systems under demonstration is based upon the definition of "Detection Halos" (circles of preassigned radius R, around the true locations of all objects, used to discriminate missed or found objects (detection is / is not within halo) from false negative (detection is not within halos). The halo radius R ideally depends upon the requirements of the remediation process (e.g. circular search capability of divers); however, it also accounts for geolocation errors and sensors' resolution. The scoring process cannot be based on a more accurate detection criterion than the geolocation error affecting: (1) the measurement of the emplacement location of the objects in the Testbed; and, (2) the position estimate provided by the system under evaluation. Therefore, detection halo radius should be set in consideration of the above errors [2], [3].

Based upon previous experiences [3], CMRE has set a target accuracy of 1.5m for Testbed Objects geopositioning. The reference instrument for measurements has been a GPS – Real Time Kinematics (RTK) installed on an annular float. An engineering test campaign has been executed, by deploying six UXO targets, each one connected to a surface buoy through a constant tension mooring system (5mm Kevlar line, 2Kg counterweight through a plastic pulley at the buoy). The GPS-RTK system on the float has been installed on each of the six surface floats, and the geographic position has been acquired (5Hz sampling) and averaged above 3 hours of time. Weather conditions (up to 2.5 m/s wind and 0.3 m/s current) during the tests where those typically found in the Testbed Area. The distribution of the geographic positions of the GPS-RTK float on each UXO target has provided an accuracy of around +-0.4m around the average position (see Figure 4). This is consistent with the results of a FEM calculation of the constant tension mooring (+-0.8m) in the most extreme wind and current condition recorded during the environmental characterization of the Testbed.

To further simplify the geopositioning phase, a second measurement system has been tested during the trials. A GPS-RTK system has been installed on the hand operated crane used to deploy the UXO and clutter objects during the Testbed seeding (see Figure 3, right side). The system was set to continuously acquire the position (5Hz sampling) during the deployment, and a timestamp could be recorded using a pushbutton, at the instant the Operator could feel slack in the lowering line (i.e. the object was touching the sea bottom). The position of the objet has been calculated by interpolating the two records before and after the timestamp. This system has proven to be extremely accurate, when compared to the results of the previous method (estimated error below 0.2m (see Figure 4) for each of the six UXO targets), and has been adopted as the primary geolocation method during the actual Testbed seeding completed in March 2023.

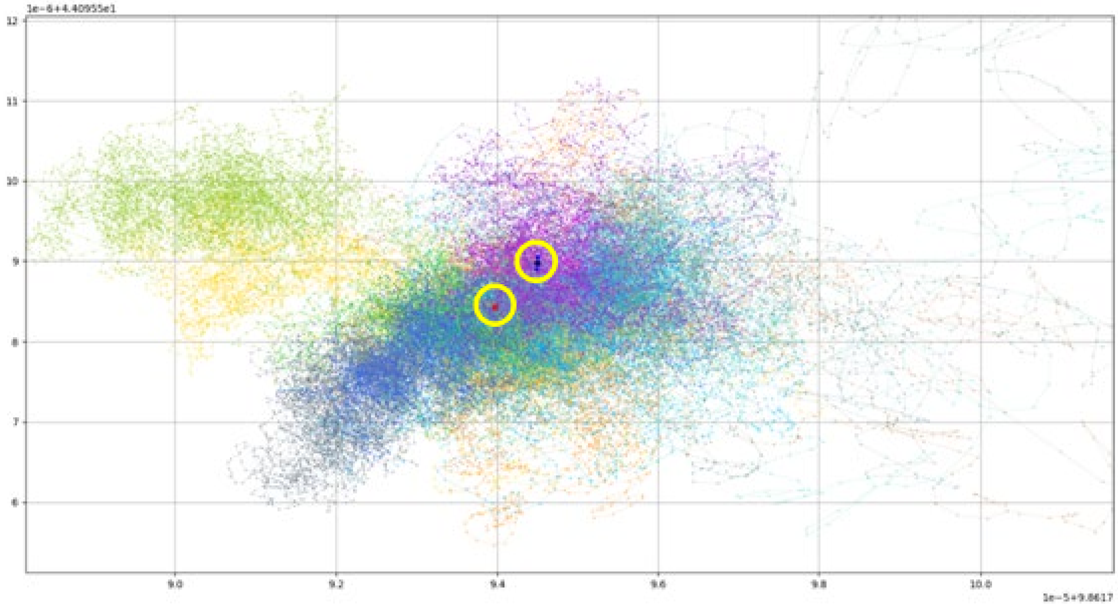

Figure 4 – Positions of the GPS-RTK Float moored atop one of the UXO Targets, sampled at 5Hz over an interval of 3 hours; the data cloud is divided in colour for every 15 minutes; the blue dot is the average position of the GPS-RTK Float; the red dot is the interpolated ("snapshot") GPS-RTK position recorded at the deployment crane pulley

The GPS-RTK geopositioning has been used to evaluate the performances of an acoustic USBL positioning system, in view of possible future implementation of a Testbed in deeper, open waters. The tests have involved a Kongsberg HiPap 352 Transceiver installed on a vertical pole on an adjacent pier, in line of acoustic sight of the Testbed, and suitable transponders on each of the six UXO targets. This method proved to be accurate in range, but not in bearing (error greater than 1m), due to non-systematic errors related to multipath (depth << range) and mechanical noise induced by the mounting. Further tests should require the USBL Transceiver to be installed on a float (boat or USV) to compensate and minimize errors.

6. THE WAY AHEAD

Lessons Learned Report - One of the objectives of SERDP-ESTCP funded projects is the technology transfer among all the stakeholders of the Munition Response Area (Demonstrators, shooting ranges and testbed Managers, remediation program Managers). In this framework, CMRE is publishing a detailed lessons learned report covering the Testbed implementation phases, based on the recommendations and practices included in the NATO Lessons Learned Handbook [4].

Systems Demonstration – The first systems demonstration at the CMRE Testbed is planned for September 2023. Two Research Institutions have applied to participate, namely: (1) the GEOMAR - Helmholtz Centre for Ocean Research (Kiel, Germany), operating an AUV equipped with HF Acoustic, Magnetic, Electromagnetic and Optical Sensors; and (2) the VLIZ (Flanders Marine Institute, Ostend, Belgium), operating and AUV equipped with LF Sub-Bottom Profiling Sonar.

CMRE Internal Demonstration - Along the Years, CMRE has deployed and utilized AUV systems with various acoustic sensors installed; ESTCP has requested us to consider deploying some of those available systems over the Site, and determine their performance.

To date, the Testbed has been surveyed using: (1) an Hydroid *REMUS100* AUV, equipped with an Marine Sonics 900/1800 kHz Side Scan Sonar (SSS); (2) a CMRE - Iqua Robotics "Sparus II" AUV, equipped with a Sound Metrics ARIS Explorer 3000 acoustic camera; and (3) a CMRE – Bluefin "MUSCLE" AUV, equipped with a Thales 270-330 kHz Interferometric Synthetic Aperture Sonar (InSAS) and a CMRE Autonomous Target Recognition (ATR) system.

Preliminary results suggest that system (1) does not provide the necessary information for UXO detection and localization mainly due to low resolution and insufficient. System (2) has demonstrated to be adequate for UXO detection, classification and possibly identification (see Figure 5). However, this system requires improved navigation for operational uses. We demonstrated the capability of system (3) to detect UXOs, however the resolution of the SAS is too small for effective classification especially for the smaller objects. Further investigation on the overall performances of the classifier is currently ongoing.

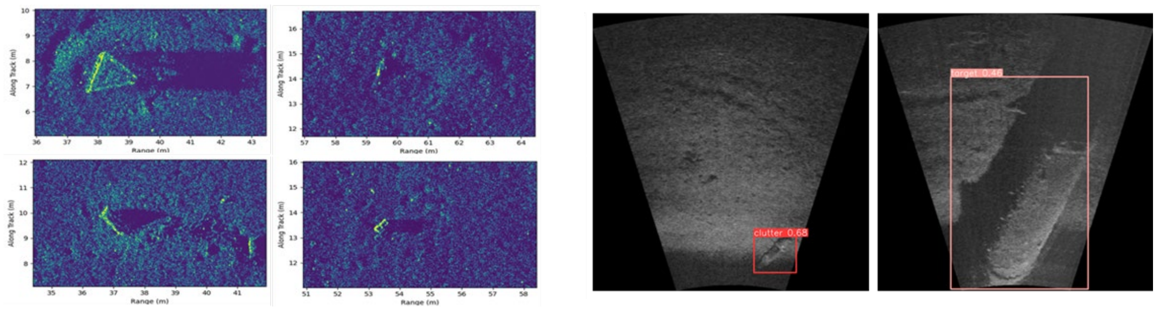

Figure 5 – Examples of (left) Muscle AUV contacts and (right) BIONDo AUV contacts

7. ACKNOWLEDGEMENTS

The CMRE UXO Testbed Project is supported by:

- Environmental Security Technology Certification Program (ESTCP, Alexandria, VA, USA), main Sponsor;
- Institute for Defence Analyses (IDA, Alexandria, VA, USA), designated scoring Authority;
- Italian Navy "Centro di Supporto e Sperimentazione Navale" (CSSN, Naval Support and Experimentation Centre, La Spezia, ITA), host of CMRE facilities and point of contact with local Maritime Authorities;
- Italian Navy "Balipedio Cottrau" (Experimental Shooting Range, La Spezia, ITA), provider of dummy and replica UXOs;
- Italian Military Establishment "Agenzia Industrie Difesa, Stabilimento Militare Ripristini e Recuperi del Munizionamento" (Noceto, ITA), provider of inert and replica UXOs.

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