Volume XXVI 2023
ISSUE no.1
MBNA Publishing House Constanta 2023

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

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To cite this article: V. Dobref, M. Tănase, A. Pintilie, G. Ichimoaei and V. Mocanu, Scientific Bulletin of Naval Academy, Vol. XXVI 2023, pg. 186-200.

Submitted: 03.05.2023
Revised: 04.08.2023
Accepted: 28.08.2023

Available online at www.anmb.ro

ISSN: 2392-8956; ISSN-L: 1454-864X

doi: 10.21279/1454-864X-23-I1-023

System based on autonomous aerial and maritime surface vehicles to identify sea mines and support the intervention team in the neutralization mission

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Abstract: As naval forces continue to be increasingly present in today's operational environment, European maritime forces are poised to successfully exploit autonomous mine countermeasures (MCM) technology, not only to save manpower but also to increase operational efficiency. Successfully detecting and removing mines from the maritime environment (especially drifting mines, which have re-emerged in the spotlight following the outbreak of war in Ukraine in February 2022) remains a key requirement for maritime forces trying to maintain the security of waterways and oceans around the world. The overall objective of the project, which is the subject of this paper, is to develop and integrate autonomous means (UAVs and USVs) into the concept of action of specialized forces for the search and identification of sea mines. As a starting point in the definition of the overall objective, it has been taken into account that the intervention of specialized forces to neutralize explosive devices involves a series of complex actions, including search, detection, identification, location-based assessment, safe destruction/neutralization, recovery, and destruction of improvised explosive devices or munitions.

Keywords: MCM, mines identification, unmanned aerial and surface vehicles

1. Introduction

Initially intended for defensive use, military forces place sea mines to deter unauthorized entry into national waters. On the offensive, sea mines are usually placed to interdict the naval resources of a ship target or an enemy passing along a projected route. Like landmines, sea mines can still be active after many years of deployment [1], [2]. The inheritance left by the recent confrontations in North Africa proves that, even nowadays, sea mines can be placed in European seas (and in any sensitive sea area where critical resources are shipped) and therefore continue to be a real and extremely dangerous maritime threat.

Threats from sea mines have forced the military to find effective countermeasures. The world's governments typically have been relying on both passive and active permanent mine countermeasures (MCM) tactics. Passive countermeasures involve modifying the specific characteristics of the target ship or its footprint. These solutions even include the use of fiberglass or wood instead of steel or even attempting to alter the magnetic field of a steel ship through demagnetization processes. Alternatively, active countermeasures aim to discover mines using special ships or platforms to avoid or destroy them.

The use of dredgers and mine hunters have two such measures: mine sweeping, mine hunting (different from sweeping). This necessitates seeking out mines in an area before removing them. The last is generally broken down into four stages: 1. Detection, 2. Classification, 3. Identification, 4. Disposal.

As mines have become sophisticated, mine countermeasures - MCMs - got more advanced. Today's naval forces use a variety of mine countermeasures. The current trend in mine search, discovery and neutralization operations is tactically to maintain human operators outside the mined field. To accomplish this, contemporary MCM forces use autonomous devices (e.g. AUVs (Autonomous Underwater Vehicle), ROVs (Remotely Operated Vehicle), surface/underwater autonomous vehicles, USVs/UUVs) with high-resolution sensors (e.g. sonars, magnetometers, cameras) equipped with computer-aided (CAD) mine detection and sorting algorithms as well as automatic target recognition (ATR) processes.

Recent solutions, which will be presented later in the paper, use not only high-tech hardware and software systems for mine-hunting operations but also biotechnology. Just as dogs and rodents can be trained to detect landmines, marine mammals, such as dolphins, are trained by the US and Russian navies to detect sea mines while keeping neutralization/destruction teams away from the minefield. The dolphins are also trained to identify and locate mines on the bottom of the sea or mines buried in bottom sediments. Dolphins are trained to use their natural bio-sound to find a target and to signal their leader, using special communication methods, if a target is detected. The operator then commands the dolphin to mark the location of the target by releasing a beacon [3]. The US Navy has reported that dolphins trained for mine clearance operations were deployed in the Persian Gulf during the 2003 Iraq war. The Navy stated that these dolphins were effective in detecting over 100 sea mines [3].

2. Sea mines Typology

In general, sea mines are explosive objects of various shapes, which can range in dimensions from 50 cm to almost 3 m and can contain from 50 kg to over 1000 kg of high explosives. Drift mines were the most frequent type of sea mine that was deployed in both the First World War and the Second World War [2]. Very versatile, drift mines can be launched from boats, warships or aircraft. Marine drift mines can be activated remotely or by contact. As the name implies, drifting sea mines remain on the seabed using negative buoyancy or are totally/partially buried on the seabed.

In order to be able to detect ships from the surface and to hit the hull of the ship floating near the surface with their explosive energy, marine bottom mines tend to be used in relatively shallow waters (less than 50 m).

The easiest to use mines, contact sea mines, are activated when a ship physically touches the mine in the water (or very close to it). The contact sea mines were equipped with many ingenious anti-sweep devices, including explosive charges to cut the sweep wire and detent devices that allow a sweep wire to pass through the anchor cable without cutting it [2]. Magnetic sea mines used the vertical component of the ship's magnetic field to activate when a certain field density was reached. In the 1930s, magnetic mines operated based on the horizontal component of the ship's magnetic field [2].

This apparently insignificant change made it possible to design a mine fuse that responded to the rate of change of field strength rather than absolute field strength. This made defense against magnetic sea mines by degaussing and magnetic sweeping procedures far less effective. Magnetic mines are available at costs between US$10,000 and US$25,000 [1]. Due to the vessel's machinery, the design of the hull, and the propellers (and many other factors), all ships and submarines have a specific acoustic signature.

This principle is used in the fabrication of acoustic sea mines. Delay clocks can be included to leave the sea mine inert (and thus unsweepable) for some days after it has been deployed, while the incorporation of counters means that the sea mine will only be detonated after a certain number of impulses have been received. This means a sweeper would have to make a large number of passes over a suspected field before it could be sure that all the mines within the field had exploded.

The cost of acoustic sea mines differs dramatically depending on the capability of its system (bandwidth). They are available at costs between US$50,000 and US$150,000 [1].

Pressure mines are invariably bottom mines since they measure the absolute drop in pressure associated with the difference between the known pressure due to water depth and the depth of water under the hull of a passing ship. This differential is directly related to the depth at which the mine is situated. Pressure mines are inevitably unsweepable, are shallow-water inshore weapons, and are specifically intended to destroy amphibious craft. They are located in such shallow water (even surf zone) that even minute pressure signatures would detonate them. Pressure mines have been adopted for an entire generation of small anti-invasion mines [2]. They are available at costs between US$25,000 and US$50,000 [1].

Magnetic mines cost from $10,000 to $25,000 [1]. Due to the ship's machinery, hull design and propellers and many other factors, all ships and submarines have a specific acoustic signature. This principle is used in the manufacture of marine acoustic mines. The cost of marine acoustic mines differs depending on its system (bandwidth). They cost from $50,000 to $150,000 [1].

Pressure-activated mines are inevitably impenetrable, are deep-sea weapons and are specifically designed to destroy amphibious craft. Pressure mines have been adopted for an entire generation of small-scale anti-invasion mines [2]. They are available at costs ranging from $25,000 to $50,000 [1].

3. Drifting mines detection

3.1 Context

International regulations require floating sea mines to be anchored and equipped with a self-destruct mechanism in case anchoring fails. When hostilities take place in more confined areas, through which more than one vessel is sailing, the probability of damage increases significantly, and floating sea mines can be transformed into a very effective anti-ship weapon. One example is the Persian Gulf, where coalition forces found a large number of drifting sea mines during the Gulf War. The effectiveness of this military tactic was obvious when the US Navy's amphibious assault carrier Tripoli was damaged by a sea mine. After this incident, floating sea mines were classified as the primary threat to US Navy aircraft carriers.

As a result, the war was considerably slowed down and risk-averse shipping companies considerably reduced their transit through the conflict zone. Since then, floating, drifting sea mines have continued to appear, as in the case of NATO's intervention in Libya in 2011. A similar concern has arisen from recent terrorist threats: floating explosive devices released in a commercial port could cause immense economic damage, although no such cases have occurred so far.

Detection methods are mainly based on sonar techniques. However, this has proved inadequate for the detection of drifting mines; on the one hand, because of the practical problem of the downward inclination of the sensor.

The expected target diameter is quite limited, as shown in Table 1, it has been demonstrated that it is possible for a human operator to visually detect the target. Therefore, an infrared video recorder can be selected for this application.

Tabel 1. Mine with their characteristics [4]

Name	Shape	Weight (in air, kg)	Dimensions (mm)	
Murena	Cylindrical	780	Lenght	2096
			Diameter	533
Manta	Truncated cone	220	Height	440
			Diameter	980
Rockan	Wedge	190	Lenght	1020
			Height	385
			Width	80

This causes great difficulty in detecting objects in the dynamic scene presented by the sea surface, even by using sophisticated background subtraction techniques such as EGMM (Enhanced Gaussian Mixture Model) and ViBE (Visual Background Extractor) [5], which are able to filter out considerable amounts of noise from an image [6].

A more useful feature to discriminate between objects and backgrounds would be the moving behavior of dynamic elements in the marine environment. As is known from wave theory, waves propagate linearly along the wind direction, while drifting mines have a vertical oscillation and slower movement relative to the undercurrent (not necessarily along the wind vector). They can both modify their shape and can disappear/appear, which makes it more complicated. Various target-based tracking strategies, e.g., mean displacement tracking [7] and particle filtering [8], could be used to create a background motion pattern. Optical flow and block matching techniques have been applied with promising results.

4. Sea mines detection. State-of-the-art, innovative solutions to search and identify sea mines

4.1 Behavior subtraction concept

A recently developed and tested innovative method is presented in the literature [10,11]. The analysis method based on a behavioral assessment by "background extraction" [10] was first described in [11]. This is a method based on the principle of evaluating and comparing behavioral patterns over a time window with a learned background model. It is relatively simple, fast in terms of processing algorithms, and easily extendable to use multiple functions. The method is based on the idea that the video sequence events should be used, not just the items in the discrete frames. Then, the characteristics of these events can be extrapolated, analyzed and used to build a background pattern and to identify and remove outliers that are not consistent with this background pattern.

The background extraction methods mentioned provide the tools to do this: they detect image change at the pixel level. State-of-the-art systems, such as EGMM or ViBE, try to minimize unnecessary detections, although, it would be preferable to have a lot of events.

Background extraction converts the video stream into a binary representation image stream, where pixels contain the value 1 if a change has been detected (therefore an event occurs) or 0 if no event occurs. Each pixel will be characterized by a behavior pattern, a sequence of 0's and 1's describing the activity in that scene. From this, a number of characteristics of the marine process can be extracted [12], [13], namely: the total activity in the time window under analysis, summing up all the activity bits within it, providing an overall measure of the event description in that pixel, and the number of transitions between activity and non-activity states, which provides some form of frequency information.

These two sets of information ideally facilitate the solution of the drifting mine problem, since both the overall motion behavior and frequency are considered features that distinguish between the mine and the surface waves.

The next step in this algorithm is to build a pattern background and a detection technique for abnormal, context-inappropriate behaviour. For this purpose, a probabilistic approach is possible [14], but also a more computationally feasible and straightforward method. For this, we compute the characteristics of the behavior for a set of training data. If only one behavior feature is analyzed, e.g. total activity in a fixed length window time, for each pixel, the maximum value of that feature can be found. The resulting image will be called the behavioral image, which represents the most likely background pattern. The outlier detection consists of calculating the online behavioral image at time t, extracting the trained background pattern from it, and scaling the result, as shown in Figure 1; hence the name 'behavioral extraction'.

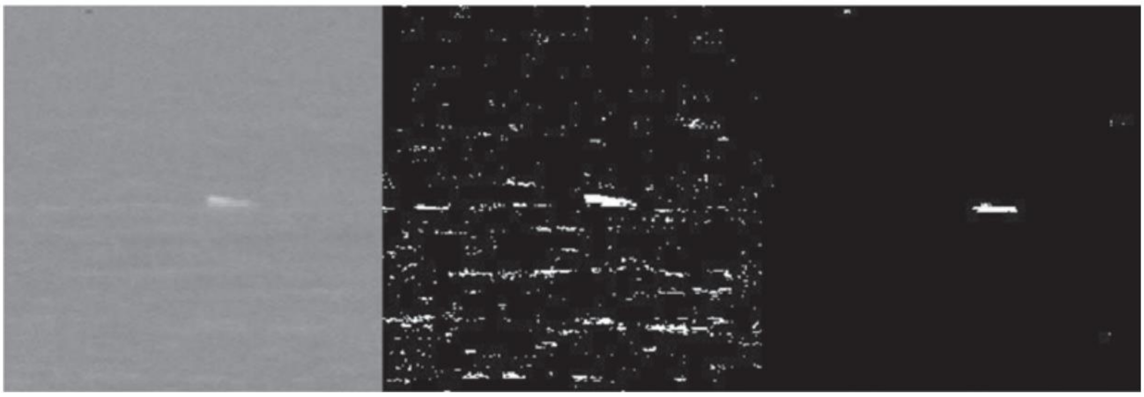

Figure 1. From left to right: IR image, activity image, background extraction [15]

Validation of the results, i.e. the performance of the algorithm on real measurements, was performed with the Elbit Micro Compass MWIR (Medium-Wave Infrared) camera system installed on a Belgian Navy patrol vessel P901 Castor (Figure 2, Figure 3).

Figure 2. Patrol vessel Castor P901 [7]

Figure 3. MicroCompass sensor [7]

Measurements with this system were made in the harbor where the patrol vessel Castor was moored. A small exercise mine was launched at a distance of about 250 m, and the camera zoom was increased to cover the full width of the dock entrance.

In this way, the target could be observed with an approximate object dimension of 6 pixels, which made detection difficult (but not impossible) for both a human observer and the detection algorithm.

The mine was launched in the middle of the dock entrance by a RHIB (Rigid-Hulled Inflatable Boat) craft and was left free to be carried by the current. The sea state was about 1-2 Beaufort, so a limited degree of wave activity, unrepresentative for sea trials. However, the tests provide a best-case scenario.

Figure 4. MicroCompass camera operator station on P901 Castor [7]

In these tests, 4 video footage sequences of the drifting mine were recorded, along with a number of sequences of swimmer and small craft activity. Figure 5 shows a snapshot of one of these video recordings. In order to evaluate the performance of the detection algorithm, ground truth annotation was performed on the mine sequences.

Figure 5. Drifting mine in the port of Zeebrugge, captured by the MicroCompass MWIR sensor on the P901 Castor [7]

The video files represent 10 minutes of filming and have been encoded in MPEG-4 format with a resolution of 720×576 pixels (25 frames per second). The background extraction behavior evaluation algorithm, which varies training sets, behavior characteristics, time window lengths, and thresholds, was applied and the detection results were compared with the actual annotated ground position of the drifting mine to obtain sets of true positive ratios TPR. These values are plotted and the resulting convex case gives us a ROC curve for each parameter set describing the performance of the algorithm. The computed ROC (Receiver Operating Characteristic) curves are shown in Figures 6, 7, and 8.

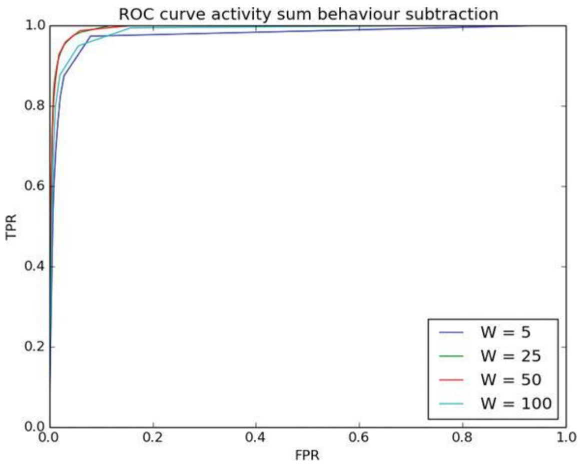

Figure 6. Comparison of activity sum behavior subtraction for different time window sizes [4]

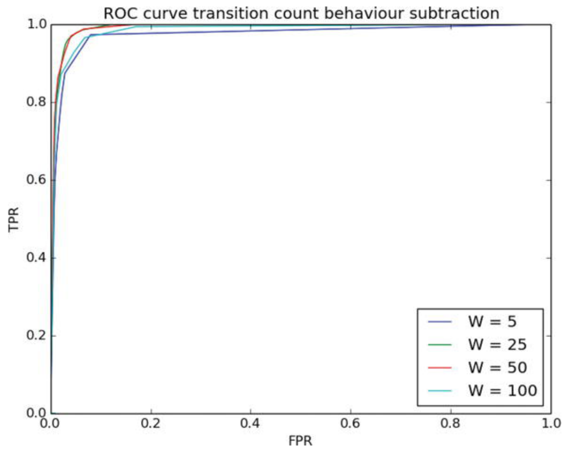

Figure 7. Comparison of transition count behavior subtraction for different time window sizes [4]

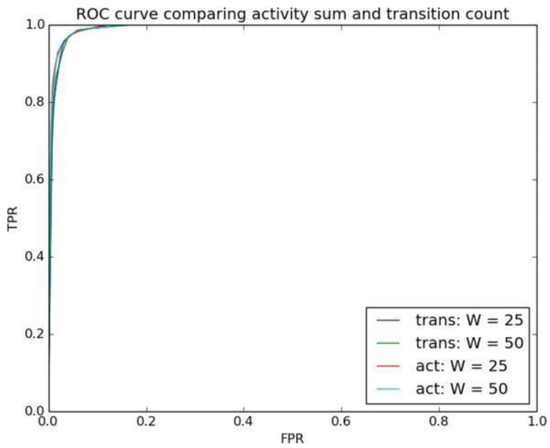

Figure 8. Comparison of activity sum and transition count for different time window sizes [4]

Frame rates of 5/25/50/50/100 were selected for evaluation, which, considering the 25 fps frame rate of Micro Compass, correspond to durations of 1/5, 1, 2 and 4s. The performance of the algorithm was evaluated by plotting the pairs TPR and FPR (False Positive Ratio) for several runs of the algorithm with different thresholds in a graph and then plotting the convex body enveloping these points.

This convex envelope is known as the ROC. Evaluating the ROC curves for behavior evaluation, using the sum-of-activity feature, it is observed that the 1 and 2-second time windows outperform the other values. It is also observed that for these values very good ROC curve results, approaching the ideal performance. If the number of transitions feature is evaluated over the same time window size, the results are quite similar.

Both behavioral characteristics work equally well, which is shown by comparing their optimal window sizes of 25 and 50 frames. These results demonstrate that it is possible to detect floating mines (and similar objects) on the sea surface using passive sensors and evaluate the behavior based on background extraction. The behavior evaluation algorithm seems to be a very suitable method for the initial detection of floating targets. Other classification procedures can be based on it, with or without human operator involvement.

To apply this arrangement as an effective operational avoidance system for collisions on a vessel in motion, a scanning setup is suggested [4], in which a stabilized camera network (thermal or optical) is scanning sampled segments of a nominated safety area for periods of 5-10 seconds.

Because of the complexity of the ocean medium, these methods have their advantages and disadvantages. Each of the methods presented [4] focuses on a specific type of marine mine and are therefore complementary. Future research should focus on integrating these techniques into an MCM system that performs a complex mission from search to neutralization/destruction using autonomous vehicles. Decision-making and computing capabilities should be incorporated on-board sensor vehicles.

4.2 Voyis project for remote mine identification

In January 2022, the first of several LAUV units were delivered to the naval base in Frederikshavn, Denmark [15]. This delivery is part of the recently signed agreement between OCEANSCAN-MST, a Portuguese manufacturer of light autonomous underwater vehicles, and the Danish Ministry of Defence's Procurement and Logistics Organisation (DALO).

LAUV - Light Autonomous Underwater Vehicle - is a robust, cost-effective, and lightweight autonomous underwater vehicle. It is designed to be simple to deploy, operate and recover by one person.

The OCEANSCAN team says of this product, "The ability to have the LAUV collect side-scan sonar data combined with depth-looking cameras is very exciting. Voyis was selected because their module can collect video images in a very dark environment and at the same time build a 3D point cloud based on those images."

Figure 9. OCEANSCAN-MST LAUV (Light Autonomous Underwater Vehicle) units with integrated Voyis technology [18]

4.3 Thales solutions: MiMap and M-CUBE

The UK and French Ministries of Defence have appointed Thales as prime contractor, responsible for the development, production and qualification of two identical prototypes.

MMCM (Maritime Mine Counter Measures) offers an innovative solution as it relies on the use of on-board vehicles and new digital technologies. Big data analytics technologies, coupled with artificial intelligence, enable highly efficient and high-performance processing of huge amounts of data from sensors carried by these vehicles.

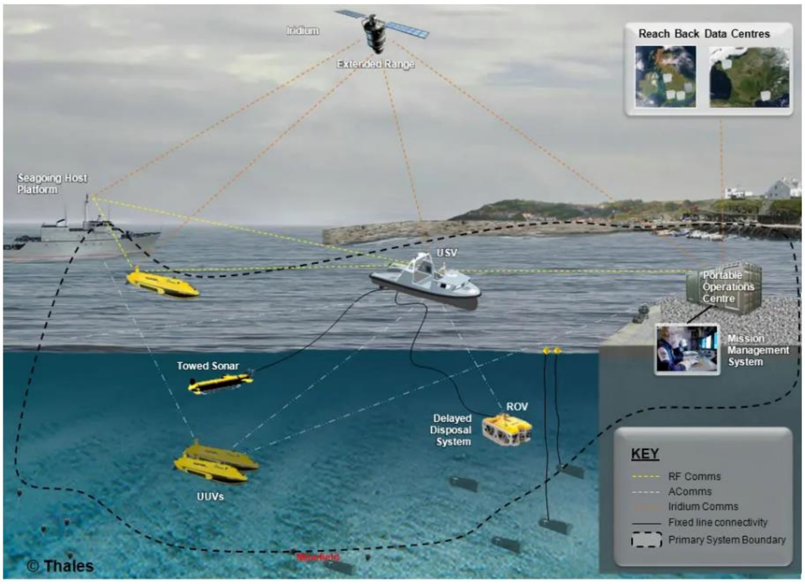

Figure 10. Mi-Map - Post-mission analysis tool [19]

MiMap [16] is a tool for mission analysis that allows the operators to examine sonar input either in real time or registered during a mission.

M-CUBE - Marine Mine Countermeasures Management Equipment

The multi-purpose M-CUBE mission platform [16] is designed on an open and modular design to ensure efficient management of the most complex operations. Incorporating latest generation technologies, its extensive functionality covers all phases of mine countermeasures missions: including planning, implementation and surveillance, assessment, information and training. M-Cube, the Mine Counter Measure mission management system is deployable on conventional MCM vessels as well as stand-alone MCM systems. Combined with MiMap, it reduces the cognitive load on commanders and operators, enabling them to make efficient and effective decisions in a threat environment. It is the most capable and agile C2 (command and control) countermeasures system. M-CUBE is easily configured to accommodate any type of sensor and includes a wide range of built-in support tools. Drastically reduces operator workload while ensuring a very high level of efficiency and safety

MiMap and M-Cube are two core systems used in the Franco-British maritime mines countermeasures program. Thus, this demonstration also highlighted the interoperability of MMCM solutions with other NATO equipment and standards.

To support the detection, classification, and location of underwater mine threats, Mi-Map provides high-speed multi-user access to a sonar database and includes an HMI (Human-Machine Interfaces) with a range of functions, from displaying and mapping sonar images to contact analysis and management.

It is optimized to perform MCM tasks quickly in either post-mission mode (Unmanned Underwater Vehicle -UUV data) or real-time mission mode (for towed sonar data). Its design allows fast navigation through huge SAS image data sets and efficient management of thousands of contacts. The two solutions, MiMap and the M-Cube command and control (C2) MCM system, have been tested in NATO's international maritime exercise Dynamic Messenger 2022 [16].

It took place in Portugal to assess the capabilities of participating naval forces to use unmanned systems to counter sea mines and submarine threats. The exercise showed that MiMap and M-Cube can interoperate with other naval components according to NATO standards.

In the exercise, Thales, MiMap and M-Cube technology was used to run a mine countermeasures exercise alongside the French Navy's explosive ordnance disposal divers and the RTSys-built sonar and navigation system for divers called Sonadive. The exercise, which involved unmanned systems deployed over an 8km² mined area, was administered by Allied Maritime Command and Allied Transformations Command. The C3MRE/CATL (Command, Control, Communication Maritime Robotic Exploitation/ Collaborative Autonomy Tasking Layer) network has interconnected various industrial solutions, including Sonadive, with NATO navies.

Thales supports the Australian Government's investment in an Australian Defence Force that is more agile, more capable, and more powerful, with a wider range of capabilities. Thales recognizes that developing a truly sovereign capability will support Australia's long-term security and prosperity by investing in the future.

4.4 Kongsberg solutions

The Recon AUV payload has been mapped on two AUV platforms - with Kongsberg Maritime on the HUGIN AUV for the Royal Norwegian Navy and with Defence Science Technology Group (DSTG) Australia on the REMUS 600 vehicle for the Autonomous Warrior demonstration [17].

Complete visual identification data, comprised of quantitative 3D laser and qualitative stills image data, can be efficiently collected for all MLOs (Mine-Like Object) in a single survey mission. Once the vehicle is recovered the data can be rapidly assessed and divers or ROVs can only be deployed to neutralize high-probability targets.

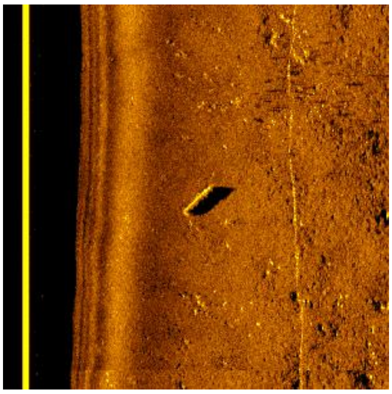

Figure 11. MLO Detection – Sidescan – REMUS [20]

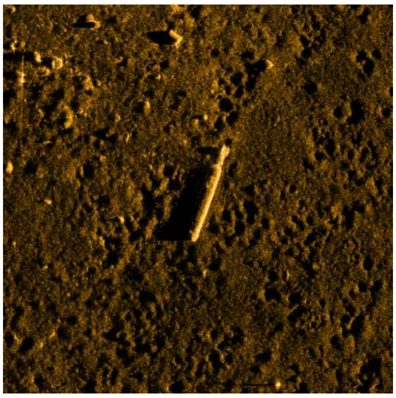

Figure 12. MLO Detection -Kongsberg HISAS [20]

The tests were carried out at the Kongsberg facility in Norway and at Jervis Bay in Australia, in areas with known MLO targets. Targets were detected and located by manual examination of the data, but the process could also be completed using shipboard or AUV-based automatic target recognition (ATR) software [17].

Figure 13. Identification, improving covertness, and reducing risk with fully submerged autonomous missions [20]

Figure 14. Vehicle integration [20]

Kongsberg HUGIN visual data was mosaicked into a large image to get a complete visual understanding, and laser data was used to directly measure target dimensions to get a qualitative understanding.

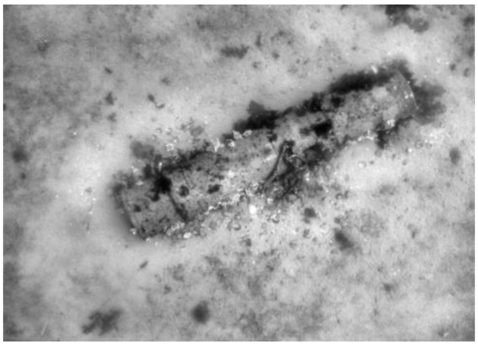

Figure 15. REMUS 600 MLO data [20]

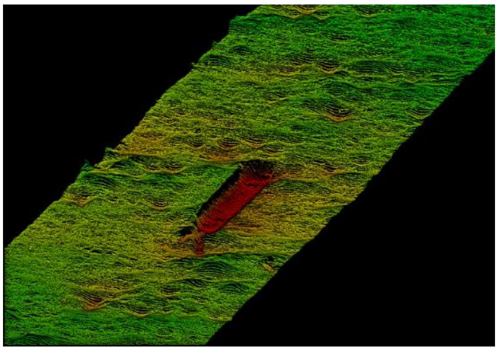

Figure16. a) Kongsberg HUGIN Visual Identification Data [20]

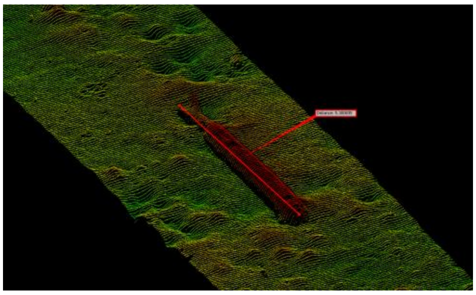

Figure 16. b) Kongsberg HUGIN Visual Identification Data [20]

Figure16. c) Kongsberg HUGIN Visual Identification Data [20]

Final outcome: The collected visual data allowed the correct visual identification of both targets from a distance, revealing an inactive torpedo (HUGIN) and an inactive cylindrical landmine (R600) [17].

5. ASMINES project developed by the Romanian Naval Forces

The overall objective of the ASMINES project is to develop and integrate autonomous capabilities (UAVs and USVs) into the concept of integrated action of specialized forces in the search and identification of sea mines. As a starting point in the definition of the overall objective, it has been taken into account that the intervention of specialized forces to neutralize explosive devices involves a series of complex actions including detection, identification, location-based assessment, safe deployment or neutralization, recovery, and destruction of improvised explosive devices or munitions.

Figure 17. Ships of the Romanian Naval Forces on missions in the Black Sea [21]

Figure 18. Drifting sea mine in the Black Sea, discovered and neutralized by the Romanian Navy in 2022 [21]

Figure 19. EOD (Explosives Ordnance Disposal) diver inspecting a drifting sea mine in the Black Sea in 2022 [21]

Figure 20. Destruction of a drifting sea mine in Romanian territorial waters by a Romanian Naval Forces EOD crew in 2022 [22]

The project, due to its scope and subject matter, will require detailed studies and research, i.e. the achievement of TRL7 technological maturity, on the following defining directions for the planned concept of operation:

- the choice and integration into the platform architecture of fixed-wing Class I (<150 kg) - Mini

(<15 kg) UAV systems, capable of performing formation flights at altitudes above 3000 m and operating distances up to 12 Mm. In view of the anticipated search area, which is characterized by a large surface area, the use of a minimum of two UAV systems simultaneously will be considered, with the possibility of increasing their number depending on the mission.

The UAV systems should be capable of being launched from the shore area or from a ship at sea, with the possibility of recovery on land, to perform autonomous flight missions, following pre-established trajectories, automatically or with the possibility of control by the human operator, in a defined sea mine search-identification area. The UAVs will be equipped with multispectral optical sensors, which will automatically capture images up to 3000 m altitude, and transmit them to the command and control station, respectively to the mission planning and control software platform (developed within the project), where, based on artificial intelligence algorithms, the images will be automatically analyzed to identify targets of interest on the water surface. Identified items will generate alerts, including on AR glasses;

- analysis and identification of the optimal version of the maritime surface platform - USV, for

the prototype autonomous system (USV) development that will meet the requirements and will be integrated into the platform architecture. The autonomous craft - USV will be based on existing naval technical solutions that can be transformed into an autonomous system, or commercial solutions will be used. The necessary technical and structural modifications will be made to the vehicle to enable remote control and the necessary mechanisms and automation will be integrated for the installation of auxiliary systems: payload, robotic arm, etc., which will enable specific actions to be carried out in order to neutralize the identified sea mine. The images taken by the sensors mounted on the USV will be processed and will provide a series of graphic indications on AR (Augmented Reality) glasses. The use of AR technology creates the advantage of image capture and the possibility to transmit images to other specialists, either on the vessel or on land, who can provide a range of information, including visual information, to response personnel;

- definition and implementation of a command and control software platform, allowing mission

planning, aggregation of data and information from autonomous systems, and data transmission in a standardized format, according to the requirements and procedures of the Naval Forces.

The application will provide the operator with all the necessary information in an intuitive and ergonomic graphical form, using AR/VR (Virtual Reality) technologies to display essential information. The platform will be equipped with software modules to automatically analyze the images transmitted by the sensors, monitor the evolution of the autonomous systems, and communicate with their control stations and with other units on the ground or on board a ship at sea.

For all three major components of the autonomous aerial and maritime vehicle-based system, for the identification of sea mines and the support of the intervention team in the neutralization mission, the following requirements will be considered:

- The choice of the constructionally optimal model of the UAV based on: range, maximum range, optical sensor performance, secure data transmission mode(s), electromagnetic compatibility with the operating environment, etc;
- Selection of the optimal design of the USV and its adaptation to the specific mission, based on: buoyancy, autonomy, range, the performance of optical sensors and the robotic control arm, secure data transmission module/channels, electromagnetic compatibility with the operating environment, etc;
- The design and implementation of the software platform, as the central element of the system, will follow the classical rules applicable to the field, so that it operates as an integrated, modular, flexible, and scalable system, made up of various modules and submodules, which will perform numerous functions. Modularity and flexibility will provide the possibility of further development of additional functionalities, which can easily call on modules already developed.

The system will be accessible for users through intuitive interfaces, which will provide the possibility to administer the system and perform most of the system functionalities. The design and implementation of the software platform will take into account the following properties:

- Confidentiality: information, services, or resources of the information system should not be available to unauthorized personnel or processes;
- Integrity: the property of maintaining the accuracy of the information, services, or resources of the information system;
- Availability: the property that information, services or resources of the information system are accessible to authorized personnel or processes;
- Authenticity: the property of ensuring the identification and authentication of persons, devices, and services of information and communication systems;
- Non-repudiation: the property that an action or event cannot subsequently be repudiated (denied, challenged).

Secondary to performing exclusively military activities, this prototype system can be used for:

- CBRN research, by integrating specific sensor modules;
- transport of documents, spare parts, medicines, or various evidence/samples from ships at sea/at anchor to shore-based departments and back;
- air and water sampling to prevent and identify pollution in harbors, oil terminals, and beyond;
- meteorological sounding, so data can be collected on: pressure, temperature, and humidity, for different altitudes offshore;
- search and rescue missions in the Black Sea.

6. Conclusions

The problem of mines drifting threat in the south-western Black Sea basin will persist until its source in the Gulf of Odesa is eliminated. The unblocking of Ukrainian ports and the resumption of grain export flows through the Black Sea was conditioned, among other things, by the assumption of the mine hazard existence and its elimination. This real issue has been at the center of the media and diplomatic confrontation between the two sides. Exactly who and how many mines have been dropped in the Gulf of Odessa is not yet known.

In the near future, the problem of discovering, identifying, and neutralizing/destroying sea mines drifting in the Black Sea can only be solved with modern search and identification systems, based either on specialized mine-hunting vessels or on autonomous unmanned aerial and surface systems, which can perform specific search and identification missions and provide important information to the military authorities in order to make the best-informed decisions for neutralizing/destroying these mines. Depending on the evolution of the conflict, solutions can be multiple: from unilateral action with international support to multinational action under the aegis of an international organization.

Essentially, whichever solution is adopted and implemented, it will take time and adequate resources for the threat of sea mines drifting in the Black Sea to be completely eliminated. This process will in one way or another affect maritime traffic and will require high consumption of resources for surveillance and mine detection of maritime communication routes in the area of responsibility of each state bordering the Black Sea.

References

[1] Morris DA. The Mine Warfare Cycle: History, Indications, and Future. Globalsecurity.org; 1997. Available

[2] Rios JJ. Naval mines in the 21st century: Can NATO navies meet the challenge? [Master's thesis]. Naval Postgraduate School, 2005, pp. 12-16

[3] US Navy Maritime Mammal Program. Available from: http://www.public.navy.mil/spawar/Pacific/71500/Pages/default.aspx (accessed September, 2015)

[4] Olga Lucia Lopera Tellez, Alexander Borghgraef and Eric Mersch, The Special Case of Sea Mines, 2017, DOI: 10.5772/66994
[5] Li X. Understanding 3D analytic signal amplitude. Geophysics. 2006;71(2):L13
[6] Hansen R. In: Kolev N, editor. Introduction to Synthetic Aperture Sonar, Sonar Systems. InTech; 2011. DOI: 10.5772/23122. ISBN: 978-953-307-345-3
[7] Mersch E, Yvinec Y, Dupont Y, Neyt X, Druyts P. Underwater magnetic target localization and characterization using a three-axis gradiometer, Proceedings of OCEANS'14 conference, Taipei, Taiwan; IEEE; 2014 278 Mine Action - The Research Experience of the Royal Military Academy of Belgium
[8] Barnich O, Van Droogenbroeck M. ViBE: A powerful random technique to estimate the background in video sequences. In: IEEE International Conference on Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. Taipei, Taiwan; IEEE; 2009. pp. 945-948
[9] Borghgraef A, Lapierre F, Barnich O, Vandroogenbroeck M, Philips W, Acheroy M, An evaluation of pixel-based methods for the detection of floating objects on the sea surface, EURASIP Journal on Advances in Signal Processing, 2010
[10] Yvinec Y, Druyts P, Dupont Y. Detection and classification of underwater targets by magnetic gradiometry, Proceedings of International Conference on Underwater Remote Sensing, Brest, France. I. Quidu et al. (ed) 2012
[11] Cheng J, Yang J. Real-time infrared object tracking based on mean shift. Progress in Pattern Recognition, Image Analysis and Applications. 2004;3287:45-52
[12] Borghgraef A, Lapierre FD, Acheroy M. Motion segmentation for tracking small floating targets in IR Video. In: 3rd International Target and Background Modeling and Simulation (ITBMS) Workshop. 3rd ed., Toulouse, France; 2007
[13] Wei Z, Lee D, Jilk D, Schoenberger R. Motion projection for floating object detection. Advances in Visual Computing. 2007;II:152-161
[14] Jodoin P-M, Saligrama V, Konrad J. Behavior subtraction. IEEE Transactions on Image Processing: A Publication of the IEEE Signal Processing Society. 2012;21(9):4244-4255
[15] Defence - Voyis - Optical Payloads For Subsea Intelligence
[16]***, https://www.naval-technology.com/news/thales-mcm-systems-nato-navies/(accessed 5.02.2023)
[17] ***, https://www2.whoi.edu/site/osl/vehicles/remus-600/ (accessed 20.02.2023).
[18] ***, https://voyis.com/danish-navy-mine-identification-with-voyis-and-lauvs/ (accessed 10.04.2023)
[19] ***, https://www.navalnews.com/naval-news/2023/01/thales-confirms-interoperability-of-its-mcm-solutions-with-nato-navies/ (accessed 10.02.2023)
[20] ***, https://voyis.com/case-study-mcm-defence/ (accessed 10.03.2023)
[21] ***, https://maritime-executive.com/article/two-more-drifting-mines-found-and-neutralized-in-the-black-sea (accessed 10.02.2023)
[22] ***, https://www.dw.com/en/experts-warn-black-sea-mines-pose-serious-maritime-threat/a-61334599 (accessed 5.02.2023).