Volume XXIII 2020
ISSUE no.1
MBNA Publishing House Constanta 2020

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

UUVs support to naval operations

To cite this article: Valerian Novac, Eugen Rusu and Ionut Cristian Scurtu, Scientific Bulletin of Naval Academy, Vol. XXIII 2020, pg.47-54.

Available online at www.anmb.ro

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

doi: 10.21279/1454-864X-20-I1-007

UUVs support to naval operations

V Novac[1], E Rusu[1] and I C SCURTU[2]

[1] 'Dunarea de Jos' University, 47 Domneasca Street, 800 008 Galati, Romania
[2] 'Mircea cel Batran', Naval Academy, 1 Fulgerului Street, 900 218 Constanta, Romania
E-mail: scurtucristian@yahoo.com

Abstract. The article analyzes the environmental conditions present in the Black Sea basin and, in this view, the opportunity of employment of unmanned underwater platforms, especially in the contested littoral area. The introductory part of the article is presented up to date UUVs platforms in use with their capabilities and limitations. Then, the paper identifies the shortfalls and opportunities to engage unmanned platforms to operate independently or paired with other undersea, surface, unmanned aerial platforms, or fixed arrays. The closing section analyzes the types of payloads, missions, and capabilities of actual vehicles, and some ways ahead are underlined, especially regarding future sensors, weapons, navigation, and underwater communications capabilities.

1. Introduction

Naval operations in all dimensions, air, surface, and underwater, require accurate information. Providing reliable information is not a simple task, especially in a contested environment, and considering the rising cost of ship operation [1].

The threat environment has shifted from "blue" to "brown water," or littoral regions, thus, new capabilities are required in the areas of but not limited to Intelligence Surveillance and Reconnaissance (ISR), oceanographic support to operations, antisubmarine warfare (ASW), mine warfare (MIW), special operations, surface operation, and base and port security [1, 2].

Nowadays, with evolving low cost and reliable technologies and miniaturization of components, this requirement is addressed by Unmanned Underwater Vehicles (UUV) [3].

UUVs encompasses two categories of vehicles, namely Autonomous Underwater Vehicles (AUVs), which are unmanned "robots" operating autonomously and Remotely Operated Vehicles (ROVs) which are controlled and powered from surface by a human operator via a copper or optical fibber umbilical [4, 5]. In other words, AUVs may be referred to as untethered and ROVs as tethered with a mother platform [6, 7]. The use of an AUV in semiautonomous mode is also possible. Features like economic efficiency, the safety of the operator, and versatility make these platforms top candidates for the future naval risky or tedious operations [8].

The similarity of payload and sensing systems with the vehicle designed for offshore industry and availability of the Commercial On The Shelf (COTS) products fuel the research and development of the UUVs system dedicated to naval applications [9].

The paper analyzes the opportunity of UUVs employment in the Black Sea concerning this basin environment factors and bathymetry.

The Black Sea is a nearly enclosed basin connected to the Sea of Marmara and the Sea of Azov by the narrow Bosporus and Kerch Straits, respectively. Its catchment area covers large parts of Europe and Asia, providing a total freshwater supply of 3 x 10^2 km^3 annually. The freshwater flux remains large in comparison to basin volume (~5.4 x 10^5 km^3), a fact which explains, along with weak water exchange of waters with the Mediterranean Sea, the low value of Black Sea salinity: about half that of the Mediterranean's. The Black Sea is a deep basin (maximum depth of ~2200 m) with a large shelf, especially northwestern sub-basin [9, 10].

Turbidity in the Black Sea is significant, especially in the western part of the basin. Black Sea turbidity is entirely or mainly due to biology (figure 1 – chlorophyll content related to biology), a lack of nutrients with a significant impact on the overall Black Sea circulation. Another turbidity contributor is the significant volume of nutrients and contaminants from the Danube, Dniepr, and Dniestr rivers along the northwestern shelf. High turbidity due to the biological activities and river sources exists in the region because stable density stratification effectively inhibits vertical mixing and ventilation of waters from the surface [11, 12, 13].

Black Sea basin is also a strategic "hot" area as the interest of at least two fundamental military forces, namely NATO and Rusia, are influencing the security agenda in the region. In this regard, concepts like UUVs are likely suitable to enable existing surface, air, ground, and underwater manned or unmanned capabilities.

These platforms become more significant, where manned platforms cannot safely operate, like shallow waters – the case of Black Sea basin with a broad shelf or under ice sheets as the case of Black Sea in some winters when sea icing occurs in the littoral area [14].

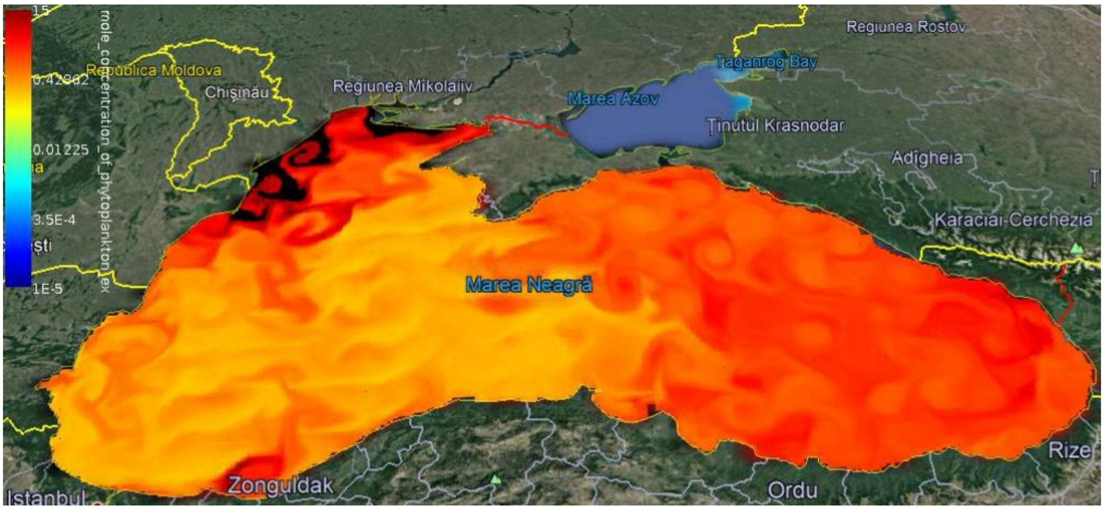

Figure 1. Mass concentration [mmol/m^3] of chlorophyll (CHL) at depth of 2.5 m in the Black Sea basin seawater on 15.08.2019 [15].

2. System design and missions

2.1 UUVs system description

UUVs should be considered systems that could integrate a human operator and vehicle subsystems and components meant to achieve optimal performance. In this regard UUVs consists of at least following subsystems:

- **mission guidance and task control** – automation allows the human operator to provide high-level, task-oriented commands instead of directly controlling vehicle functions. Future developments allow the vehicle to reconfigure and adapt mission based on internal or external factors;

- **communications –** critical and one of the most challenging subsystem – ROVs use copper or optical fiber umbilical while AUVs use acoustic links. UUVs can communicate with mother or companion manned or unmanned immersed or surface platform, Unmanned Aerial Vehicles (UAVs), Unmanned Ground Vehicles (UGVs) and fixed arrays;
- **data processing** – regulate various flows of data from vehicle control sensors and payload sensors;
- **navigation and positioning –** similar challenges with communications subsystem - use diverse sorts of sensors: acoustic, electro-optical, inertial guidance systems, and the Global Positioning System;
- **energy –** practical, safe and high-density sources are required to improve UUVs performance;
- **propulsion –** technology mature enough, less improvement are likely for this subsystem;
- **payload** – borne by vehicles for performing mission tasks consists of the following elements:
  - *sensors* – others than those used for guidance and control. They are used to gather data and consist of different acoustic, optical, chemical, conductivity, temperature, and depth sensors; fluorometers and transmissometers; magnetic field sensors; gravity sensors; and current meters. Significant advances are expected for all sensors still acoustic and optical may get preference due to broader utility;
  - *task-performance* - comprise of manipulators and other tools. The future advances are predictable in control methods, and space program research is a potential development opportunity.
- **launch-and-recovery** – platform limited though can be developed to be more general;
- **monitoring and diagnosis** – mainly Built-In Self Test (BIST) or Built-In Test Equipment (BITE) principles are adopted to detect and isolate failures among vehicle subsystems along with triplex or quad-redundant processors [1, 6].

2.2 UUVs types

UUVs were developed in various shapes and dimensions. Up to date literature identify, taking in consideration vehicles hull diameter, following categories:

- *micro UUVs - diameter (dia) < 6 inches (in)*, being inexpensive can be deployed in large number as weapons, to interfere/disrupt adversary actions or to survey the ocean floor;

- *small UUVs - ~ 12 in dia,* surveillance, minehunting and attack missions;

- *medium UUVs - ~ 21 in dia,* usually launched from submarine torpedo tubes, can conduct mining, offensive operations or jamming;

- *large UUVs - ~ 80 in dia,* amplify submarine sensor reach and enlarge their payload capacity being able to deliver payloads in areas not accessible for submarines;

- *extra-large UUVs - > 80 in dia,* launched from big ships with well decks or from the shore, intended to conduct long-endurance missions or serve as "trucks" for payloads delivery.

Figure 2. Small UUV (~ 10 in dia) designed for shallow waters, harbour and coastal surveillance [16]

Regarding autonomy technology available, the AUVs fall under bellow categories:

- **scripted** - preplanned script with embedded physical models - smart and guided munitions - “point, fire, and forget” - no operator interaction after they are launching;
- **supervised** - part or all of the functions are automated. Planning, sensing, monitoring, and networking activities associated with an autonomous vehicle, while decision belongs to a human operator along with interpreting sensors data, identify system faults, and team up with other systems;
- **intelligent** - autonomy technology to entrench attributes of human intelligence in the software of autonomous vehicles and their controlling elements. This software does the following:
  - makes decisions;
  - perceives and interprets sensed information;
  - diagnoses vehicle, system, or mission-level issues detected;
  - collaborates with other systems using communications networks and protocols [1].

2.3 UUVs missions

UUVs do not belong only to a military area of interest, also sectors like offshore oil and gas industry, marine research or environment protection agencies, salvage and search and rescue services, oceanographic services being just a part of areas where these vehicles adjunct manned platforms or fixed arrays. Payloads of UUVs for offshore industry or salvage services do not differ much from the ones used in military unmanned platforms conducting surveillance of a minefield [7, 17].

In naval operations field, the attention of researchers is concentrating mainly on following areas of interest:

- mine warfare (MIW);
- anti-submarine warfare (ASW);
- intelligence, surveillance, and reconnaissance (ISR);
- oceanographic support to operations (OSO);
- electronic warfare (EW), acoustic jamming, and decoy.

The table below highlights the most significant tasks that can be conducted by UUVs in the Black Sea environment context. More about technical constraints related to the said basin presented in the next section.

Table 1. Most important missions of UUVs [1, 3, 6, 7, 17, 18,]

Task / **Operational area**	**MIW**	**ASW**	**ISR**	**OSO**	**EW, ac. jamming, decoy**
Acoustic jamming and decoy					■
Picket sensors	■	■	■	■	■
COMMINT (communications intelligence)		■	■		
ELINT (electronic intelligence)		■	■		
Payload delivery (upwards & downwards)	■	■	■	■	■
Reconnoiter of surf, shelf and harbor area including ice sheets	■	■	■		
EW (electronic jamming)					■
Provision of bathymetry, sea state, and water column properties data				■	
Seafloor survey, classification, mapping, and profiling	■		■	■	
Mines/Minefields detection, classification, mapping, and disposal	■		■		
Targets detection, classification, hunting		■	■		
Defensive actions		■			
Show of presence – area patrol		■	■		
Submarine tag, track & trail		■			
Disruption of adversary actions	■	■			

3. SWOT analysis

The analysis below is completed taking into consideration Black Sea basin environment factors.

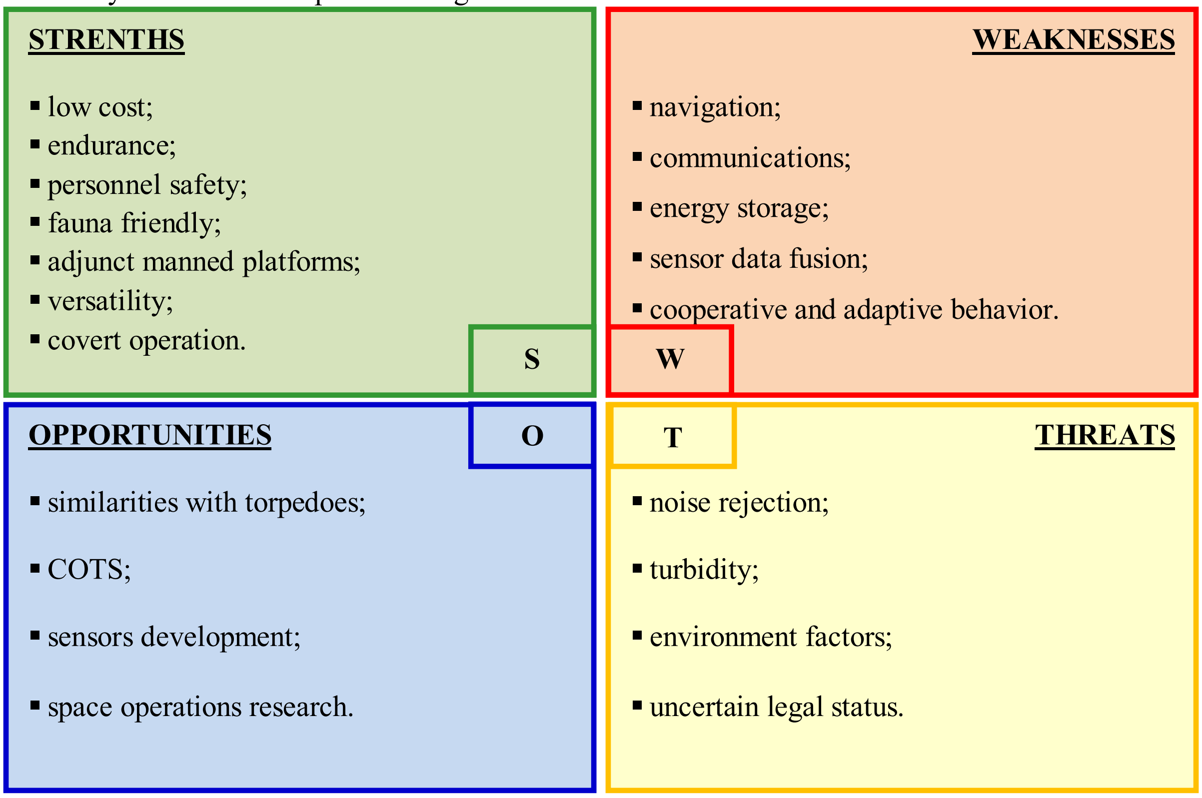

Figure 3. UUVs employment SWOT analysis

STRENGTHS:

- *low cost* – the economic efficiency of these vehicles is triggered mainly by the availability of COTS, the similarity with equipment used in adjacent domains and not at last research in other domains (space domain – payload subsystems) [4, 8, 17, 18];
- *endurance* – UUVs can conduct tedious patrols or can track and trail submarines for weeks or even months depending on energy storage capacity or ” refueling” arrangements available [1, 4, 8];
- *personnel safety* – unmanned platforms conducts dangerous tasks, like minefield reconnaissance, mapping or disposal without risking sailor lives [1, 8];
- *fauna friendly* – the recrudescence of UUVs navies are encouraged to close their programs which involve marine mammals in mine detection [8];
- *adjunct manned platforms* – UUVs have reached the deepest ocean waters (AUV/ROV Nereus – 11.000 m); they can easily operate in surf area, shallow water, harbors area or under ice sheets (is the case of the Black Sea with a broad shelf and freezing waters during some winters) [2, 7, 14];
- *versatility* – UUVs can operate in various configurations depending on mission requirements – some of them can operate both as ROV or AUV, most of them can change the payload, can get inputs from mother ships, fixed arrays, UAVs (Unmanned Aerial Vehicles) and UGVs (Unmanned Ground Vehicles) or deliver sensors [6, 17, 18];
- *covert operation* – due to their proportions and reduced acoustic and magnetic signatures, these vehicles are appropriate candidates for clandestine operations, being difficult to detect with amendments for ROVs or AUVs during snorkel immersion [1, 7, 18].

WEAKNESSES

- *navigation* – in UUVs operation navigation is a crucial factor impacting not only the vehicle positioning but also sensor precision. For increased accuracy, UUVs are required to work paired with other manned or unmanned vehicles or to get some reference inputs from fixed arrays as acoustic data transmission is weak, especially in high turbidity waters or where significant rivers run-off is present like Black Sea basin. However, new navigation methods like inertial navigation systems using laser ring gyroscopes curb said shortfalls [1, 7, 14];
- *communications* – the underwater domain being electromagnetically opaque, acoustic communications is most appropriate, but this comes with some drawbacks like reduced bandwidth and significant acoustic signature. AUVs require to dock to a fixed post/mother ship to receive orders or to download sensors data or to deliver to surface a buoy or antenna to receive/transmit data. The latest research indicates LIght Detection and Ranging (LIDAR) as a solution for future systems. Both LIDAR and acoustic face inconveniences in shallow or high turbidity waters [1, 6, 14];
- *energy storage* – small vehicles are not able to carry significant energy sources; thus, they have reduced autonomy. A solution to curb this shortfall is to dock exhausted vehicle to fixed post to recharge their batteries – figure 4 - Forward Deployed Energy and Communication Outpost [1];

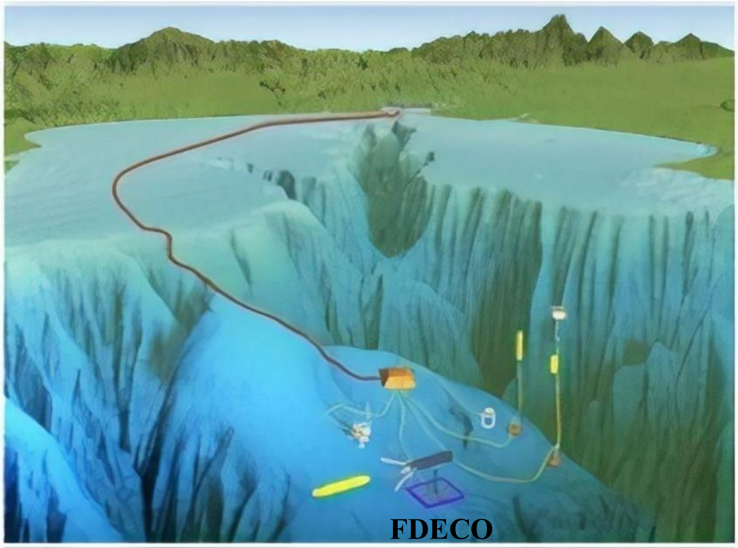

Figure 4. Forward Deployed Energy and Communication Outpost [19]

- *sensor data fusion* – at the actual stage of development, the data fusion is done by another platform or mother ship. However, the research in this field is advanced, and platforms onboard data fusion capable shall be developed soon [1, 4, 14];
- *cooperative and adaptive behaviour* – the simultaneous control and cooperation between two or more UUVs remain a challenge. The same issue with UUVs ability to adapt intelligently to environment or tactical situation changes [5, 7].

OPPORTUNITIES

- *similarities with torpedoes* – UUVs and torpedoes have much in common especially concerning hull and propulsion, and these similarities enable future research and technological transfer [4];

- *COTS* – availability of commercial components lower the price of these vehicle enabling swarms operations of small UUVs or even considering replacing an out of fuel/battery vehicle [4];
- *sensors development* – as many industries use similar sensors, e.g., electro-optical (EO) sensors for surveillance are joint in military applications, offshore industry, salvage, the research in the area is advancing very fast [1, 14, 17] ;
- *space operations research* – this sector complements the development of UUVs task performance subsystem [6].

THREATS

- *noise rejection* – especially in shallow waters area, ambient noise diminishes the performance of communications, navigations and all acoustic equipment [17];
- *turbidity* – seriously affect all acoustic and EO equipment with a negative impact on navigation, communications and sensing [7, 12, 13, 14];
- *environment factors* – though they operate submerged, the vehicles are still influenced by surface waves, currents or debris [3];
- *uncertain legal status* – despite the substantial employment of these vehicles, their definition is still not clear, the legal status when operating or entering accidentally or intentionally into another state territorial water [7].

4. Concluding remarks

The UUVs technology is mature in the majority of aspects; the vehicles used in naval operations, and some adjunct areas technological transfer is possible.

The vehicles and their payloads are similar to the ones used in other domains, and COTS are available, which led to a reduce cost of research and manufacture.

There are still some areas where researchers are still working to find solutions: navigations, communications, cooperative and adaptive behavior, and not the last legal status, and the definition of these vehicles shall be clarified.

For the future is expected as the sector to grow up and UUVs use to be extended to other naval operations presently not addressed.

References

[1] National Research Council 2005. *Autonomous Vehicles in Support of Naval Operations*. Washington, DC: The National Academies Press, [crossref];
[2] Novac V, Rusu E, *Black Sea littoral military operations - environment impact*, Scientific Bulletin of Naval Academy, Vol. XXI 2018, pg. 607-616 [crossref];
[3] National Research Council 1997. *Technology for the United States Navy and Marine Corps, 2000-2035: Becoming a 21st-Century Force: Volume 7: Undersea Warfare.* Washington, DC: The National Academies Press, [crossref];
[4] National Research Council 2000. *An Assessment of Undersea Weapons Science and Technology.* Washington, DC: The National Academies Press, [crossref];
[5] Sahu B K, Subudhi B, *The State of Art of Autonomous Underwater Vehicles in Current and Future Decades,* 2014, First International Conference on Automation, Control, Energy and Systems (ACES), pp 1-7;
[6] National Research Council 1996. *Undersea Vehicles and National Needs.* Washington, DC: The National Academies Press, [crossref];
[7] Wynn R B, Hunt J E, *Autonomous Underwater Vehicles (AUVs): Their past, present and future contributions to the advancement of marine geoscience,* Marine Geology, 352 (2014), pp. 451–468;
[8] https://dronecenter.bard.edu/underwater-drones-updated/ accessed on 01.02.2020 at 15.50;
[9] Novac V, Rusu E and Stăvărache G, *Black Sea naval accidents – intervention management,* Mechanical Testing and Diagnosis, 2019 (IX), Volume 2, pp. 11-14, [crossref];

[10] Novac V, Rusu E, *Black Sea oil spills – preventive and remedial actions***,** 19th International Multidisciplinary Scientific Conference – SGEM 2019, Conference Proceedings, vol. 19, issue 3.1, pp 683-690, [crossref];
[11] Stanev E, *Understanding Black Sea Oceanography*, *An Overview of Recent Numerical Modeling,* Oceanography, Vol.18, No.2, 2005, pp. 56-75;
[12] Kara A, Wallcraft A J and Hurlburt H E, *Sea Surface Temperature Sensitivity to Water Turbidity from Simulations of the Turbid Black Sea Using HYCOM,* Journal of physical oceanography, 2005, Volume 35, pp. 33-54;
[13] Kara A, Wallcraft A J and Hurlburt H E, *A New Solar Radiation Penetration Scheme for Use in Ocean Mixed Layer Studies: An Application to the Black Sea Using a Fine-Resolution Hybrid Coordinate Ocean Model (HYCOM)*, Journal of physical oceanography, 2005, Volume 35, pp. 13-32;
[14] Damian R G, Jula N and Pațurcă S V, *Autonomous Underwater Vehicles – achievements and current trends,* Scientific Bulletin of Naval Academy, Vol. XXI, 2018, pg. 85-89;
[15] http://marine.copernicus.eu accessed on 02.02.2020 at 10.00;
[16] www.ecagroup.com accessed on 03.02.2020 at 10.00;
[17] Bovio E, Baralli F and Cecchi D, *Autonomous Underwater Vehicles For Scientific And Naval Operations*, IFAC Proceedings Volumes, Vol. 37, Issue 10, 2004, pp. 1-11;
[18] N Polmar, *The new approach to mine warfare,* Proceedings, 2015, Vol. 141/7/1,349, pp.86, 87;
[19] https://www.thinkdefence.co.uk accessed on 04.02.2020 at 10.10.