Underwater surveillance of Romanian littoral areas using AUVs - Sea trials results

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Abstract. One of the many military as well as civilian potential applications regarding autonomous underwater vehicles (AUVs) is detection, localization, tracking and identification (DLTI) of risk factors in littoral areas. Using AUVs in underwater surveillance involves some specific capabilities like underwater data acquisitions, on-board data processing, underwater and surface communication, autonomy aspects and so on. In order for an AUV to be capable of conducting underwater environment surveillance (detection, monitoring) in littoral areas like harbors, coast objectives, ship anchorage areas, mandatory pass points and also to provide warnings about the presence of underwater and surface dangers in the interest areas, it must be first subject to sea trials. This paper presents the theoretical and experimental approaches and results for the surveillance of Romanian Littoral Areas using an AUV.

1. Introduction

The Black Sea is considered to be the eastern maritime border for both the European Union (EU) and the North Atlantic Treaty Organization (NATO). Romania like every member state within EU&NATO holds and will continue to hold responsibilities in the area of maintaining the security and counterattacking eventual threats in the maritime border.

Underwater surveillance, for the purpose of this paper, consists in the task of monitoring the underwater environment for potential risk factors. Risk factors can be defined as internal or external elements, situations or conditions that may, by their nature, affect the security of the country, resulting in adverse effects or attainment of its fundamental interests.

The field of underwater robotics has reached an impressive technological momentum over the past decades by merging areas such as electrical, mechanical and systems engineering. A particular interest is presented by autonomous underwater vehicles (AUV), given the progress in the implementation of revolutionary technologies to overcome the challenges associated with autonomous operation in the underwater environment.

Nowadays the concept of using AUVs among complement traditional existing high-value assets as, helicopters, fixed hydrophones systems etc. for ensuring the underwater maritime borders security is being implemented with success. Some of the most common military applications for AUVs are mine countermeasure (MCM), antisubmarine warfare (ASW) and harbor protection.
2. Underwater surveillance scenarios for AUVs

There are several representative features that could be used to draw up scenarios of possible risk factors that will imply the need of surveillance in littoral areas. Based on different combinations of threats, locations, targets and tactics there could be defined plausible scenarios. An example of these scenario features are presented in table 1.

| Threats | Locations | Targets | Tactics |
|---------|-----------|---------|---------|
| Destruction of harbors, ships, drilling and extraction platforms, etc. | Harbors | Military or commercial ships | Explosives in suicide ships |
| Undermining economic activities | Stationary or deployment areas | Oil platforms | Crash / hitting ships |
| Destruction of the environment | Mandatory crossing points | Ferries / cruise ships | Missiles launched from ships |
| | Roads and passes | Port areas | Marine mines and / or improvised explosive devices |
| | Natural Reserves or Tourist Areas | Waterways | Diversion divers |

To be able to use AUVs in underwater surveillance first you need to have good knowledge of the environmental conditions (propagation, position of natural obstacles, fund profile, statistical properties of clutter, etc.).

The second aspect to take into consideration in underwater surveillance when using AUVs is the sensors with which it is equipped like sonar (passive or active). Also from the perspective of the sensor used in the detection and identification process there must be considered the characteristics of the target like target strength or target hydroacoustic signature.

Passive sonars have the advantage of covertness but present some challenges when used in littoral areas where the level of ambient noise is high due to ship traffic and biological activity. In passive sonar systems, the searcher listens for the week acoustic signals generated by the target itself.

When using active sonars, the ambient noise issues are overcame because the sound intensity levels of the echoes tend to be higher than typical ambient noise levels. Active sonar systems create a pulse of sound in the water and then listen for the echo bouncing off the target.

In either case, the structure of the sound speed environment radically affects the propagation paths of the sound energy. Knowledge of the sound propagation model is required to correctly set the sonar system and to choose the appropriate tactics to locate the target.

Table 2 presents such data from the perspective of detection (active or passive).

| Target | Speed [kts] | Action depth [m] | Target strength [dB rel. 1 µPa/1 m] | Generated noise level |
|--------|-------------|-----------------|-------------------------------------|----------------------|
| Diver  | 0.5 - 1     | 1 - 20          | 25                                  | Low                  |
| Torpedo| 10 - 50     | > 20            | -20                                 | High                 |
| Mine   | -           | 5 - 10          | -15                                 | -                    |
| AUV    | 2 - 5       | 5 – maximum zone depth | -20                                 | Low                  |
The sound speed depends on temperature, salinity and pressure variation of the marine environment. The Black Sea Basin presents some specific characteristics like the interaction between the upper and lower layers causing a non-uniform structure of the marine environment. The temperature and salinity of the seawater layers in the area of the continental platform, corresponding to the Romanian shore, does not remain constant during the entire year. It is worth noting the average low salinity in this area with limit values in the vicinity of the mouth of the Danube River (phenomenon of dilution).

All these factors influence the attenuation of the acoustic signal propagation in seawater. The sound propagation in the seawater depends on sound speed profile, sedimentological sea floor structure (seafloor reflections) and marine medium attenuation.

3. Sea trials

The tests were conducted in an area (see figure 1) where:
- noise caused by naval traffic is low;
- no large variations of the thermal and saline environment;
- positioning of the reference buoys and targets can be done easily and with relatively high accuracy;
- depth and bottom type are already known data.

The specificity of the testing area is given by:
- naval traffic was only random occasional crossings of leisure craft to/from Limanu Harbour and RHIB boats belonging to RO Navy;
- there were no large variations in the thermal and saline (salinity around 19 PSU, surface temperature around 19 –22 0 C);
- depth of around 11 m, bottom generally composed of peat and covered with mud, only in the southern area having some rocks.

In the sea trials there was deployed a man portable AUV equipped with pressure sensor, magnetic compass, three-ax accelerometer and side scanning sonar. The AUV was integrated by the Research Center for Navy within a national funded research project. The AUV and sonar main characteristics are presented in table 3 and table 4.
Table 3. AUV specification.

| Items                              | Specification     |
|------------------------------------|-------------------|
| Vehicle weight in air              | 25kg              |
| Energy and endurance               | 8h/2Nd            |
| Maximum speed                      | 4Nd               |
| Surface navigation                 | GPS               |
| Underwater navigation              | Magnetic compass  |
| Payload                            | Side-scan Sonar   |
| Maximum immersion depth            | 100 m             |
| Connectivity                       | WiFi (while at surface) |

Table 4. Side scan sonar specification.

| Items                              | Specification     |
|------------------------------------|-------------------|
| Frequency                          | 450 kHz center frequency(430-470 kHz) |
| Pulse duration                     | 400µs             |
| Signal processing                  | Compressed pulse(CHIRP pulse) |
| Hydro-acoustic sensors             | 2 side sensors attached to the AUV |
| Dimensions(Length x width x height)| 432 x 41 x18 mm   |
| Directivity characteristics each sensor(VxO)| 60° x 0.5° (-3dB) |
| Coverage area                      | 1m….100m on channel |
| Emission power level               | <210 dB rel. 1µPa/1m |

Theoretical and practical evaluation of the discovery capabilities of underwater targets by the side scanning sonar fitted to the AUV has been conducted for the scenario that involves the detection of two fixed target (mine) with the target strength -20 dB, at a depth of aprox.12 m. The sea trials were conducted in July and the sea state was SS0 (according to the Sea State Code, sea like a mirror, wind less than one knot, average wave height 0).

The target detection probability for this scenario is presented in figure 2.

Figure 2. Detection probability distribution.

The equipment used in the sea trials (figure 3) were:

- MP-1 target (portable mine, ballasted version);
- Large target (cylinder Φ = 280 mm L = 700 mm).
The AUV performed 7 missions, of which one surface mission and 6 missions on the same route, but with variable dives at different points along the route. A depth variation from these missions is presented in figure 4 and the sonar mosaic from the AUV traveled path is shown in figure 5.

**Figure 3.** Targets used for sea trials.

**Figure 4.** Depth variation in two different missions.

**Figure 5.** Sonar mosaic from surface and immersion navigation.
Details about the contact (underwater target) can be obtained through operator interpretation of the data and this is why it is considered that the experience is crucial when trying to obtain data as close to real as possible (figure 6 and figure 7).

Figure 6. Sonar contacts.

The details of the two contact on the side scan sonar are presented in table 5.

Table 5. Side scan sonar specification.

| Contact | Position of Contact | Size of Contact | Size of the selected area | Image |
|---------|---------------------|----------------|--------------------------|-------|
| 1       | Latitude: 43.8047858200479 Longitude: 28.557099387344 | Width(m): 2.88 Height(m): 6.17 | 0.3622783 Height(m): 1.23304 | ![Image 1](image1.png) |
| 2       | Latitude: 43.8048365887958 Longitude: 28.5570673237462 | Width(m): 1.97 Height(m): 2.58 | 0.2014776 Height(m): 0.966433 | ![Image 2](image2.png) |
4. Conclusions

In missions in which the evolution of the AUV is required only at the surface, it follows the programmed route, compensating based on the information from GPS, magnetic compass and accelerometers any deviations due to waves, currents, etc. In immersion developments, in the absence of a Doppler loch (DVL), the compensation of current deviations due to currents could no longer be performed accurately. This fact causes, in perspective, errors in the geo-referencing of the images obtained by means of the sonar with lateral scanning.

Naturally, fluctuations in the speed of travel (imposed by the program or due to the attempt to keep on the road - counteracting the effect of waves, currents, etc. -) occur fluctuations of the instantaneous power consumed.

Analyzing the conducted missions has shown that the sonar has remarkable performance, allowing that at 3-4 meters from bottom to be able to identify reduced dimension targets. We find that the working
frequency of the side scanning sonar is low enough so that it reduces propagation losses. Analyzing the characteristics of the side scanning sonar allows us to conclude that it has good performances (very good resolution, relatively low operating frequency).

For TS = having high values (over 10 dB rel. 1 μPa/1m) – the probability of discovery of the target is above 98% within the limit of the sonar maximum range (adjustable between 20 to 100m), no matter what environment conditions, bottom nature, depth and AUV activity conditions (immersions between 10 and 45 m).

It is useful to measure the sound speed velocity in the mission area and to use the value recorded for this parameter in the mission planning software.

It is necessary to carry out a program to assess the capabilities of discovering a wide range of submarine targets (wrecks, predefined targets - exercise mines, torpedoes, etc.) for the autonomous mobile underwater platform. For a better appreciation of these capabilities, it would be necessary to equip the AUV with a video camera or to mount such equipment on the target to be detected / identified.

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