Concept demonstration of an ASW barrier using low-cost unmanned systems

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Abstract: *The use of Maritime Unmanned Systems (MUS) in modern warfare has taken a flight over the past years. Advancement of technology in autonomous data processing and underwater communication and navigation is opening doors to more complex applications such as Anti-submarine Warfare (ASW). Traditional manned ASW capacity typically comes with high operational costs, limited availability and vulnerability in high-risk areas. By leveraging new technologies, augmentation of existing ASW capabilities with low-cost, unmanned systems can serve as a force multiplier. A particular use case in this context is the development of an autonomous NATO ASW barrier designed for near-future, small-scale conflicts. For this purpose, a network of static and dynamic nodes function as a 'trip-wire' that is triggered when a submarine crosses it. One or more active dipping sonars combined with passive nodes perform multi-static Doppler-based detection of (slow) intruders. At REPMUS 2024 a concept implementation of such an ASW barrier has been successfully demonstrated in collaboration with other NATO partners. Experimental passive bottom nodes were deployed on the seabed together with a surface vehicle equipped with dipping sonar. All assets performed fully autonomous on-board target detection, tracking and acoustic communication of results using the Smart Adaptive Long and Short-range underwater Acoustic Network (SALSA) protocol stack. Interoperability between assets of the different NATO countries was achieved through the use of the Collaborative Autonomous Tasking Layer (CATL) protocol, allowing target prosecution by other partners. The experiments demonstrated the potential of the use of unmanned systems for augmenting traditional ASW capacity. This paper will elaborate on the implementation of this system-of-systems and show achieved results.*

Keywords: *ASW, ASW barrier, unmanned systems, dipping sonar, multi-static sonar, autonomy, underwater communication*

1. INTRODUCTION

The geopolitical developments of recent years have put Anti-Submarine Warfare (ASW) high on the agenda as a key capability in naval warfare. Modern ASW faces new challenges, however, such as widespread availabilities of technologies that enhance submarine stealth but also challenges in recruitment of personnel required to expand forces [1]. And although technological advancements have improved submarine detection capabilities, the high costs of state-of-the-art frigates limit their availability. As a positive development, technology in the field of marine robotics is becoming more mature. Hurdles such as underwater navigation, underwater communication and autonomy are gradually being tackled, as demonstrated by the rapid introduction of unmanned systems in fields like Mine Counter Measures (MCM). In this paper, another step in the application of Maritime Unmanned Systems (MUS) is taken by investigating their potential for augmenting traditional ASW assets.

In addition to the already existing challenges in MCM, in ASW one is dealing with a mobile, stealthy threat operated by skilled personnel. At the same time, the geographical scales of the areas to be monitored are substantially larger than in MCM. This will require sensors with substantial detection ranges to make their use worth the efforts. Still, successful augmentation of traditional assets by MUS will reward itself by enhancing detection capabilities through parallel deployment of low-cost systems. Additionally, by deploying MUS as forward detection units, frigates can operate outside the range of enemy submarines, making ASW operations safer and more efficient.

In this context The Netherlands is conducting a study to evaluate the performance of a system-of-systems, referred to as a NATO ASW barrier, consisting of static and dynamic nodes that prevent hostile submarines from crossing designated lines. This virtual barrier is intended for monitoring chokepoints, establishing harbour blockades and protecting mobile sea bases against mobile adversaries. Building up the barrier from small, low-cost assets should make the solution scalable and labour-extensive. At the REPMUS '24 exercise in Portugal a successful demonstration of an implementation of this concept was given. In this paper we will elaborate on the details of the setup and provide experimental results. Particular attention will be given to the fully autonomous multi-static sonar processing chain; dedicated underwater communication protocols and interoperability with the collaborating NATO partners.

2. CONCEPT

Fig. 1 depicts an overview of the full engagement chain of our envisioned implementation of an ASW barrier for an example scenario in which an enemy submarine intends crossing a chokepoint or exiting a harbour. Initially, detection of potential intruders is performed using a combination of active and passive assets. After detection, handover of contacts is done to allow confirmation by other sensors such as sonobuoys or Unmanned Aerial Vehicles (UAVs) carrying a Magnetic Anomaly Detector (MAD). In case of positive confirmation, engagement can be done to refrain the hostile submarine from continuing its mission. In this paper, the emphasis will be on the detection phase up to handover for confirmation.

Certain design decisions were made in earlier studies [2][3] to make this proposed solution scalable and remain low-cost. The barrier uses active (multi-static) sonar for target detection. The reduction in passive signatures of modern submarines would put too high a limitation on the detection range when simply relying on passive sonar. Doppler-sensitive pulses transmitted by the active source(s), are used in combination with passive, man-portable, stationary nodes, which allows detection of slow intruders and strongly alleviates reverberation limitations that would otherwise be experienced as a consequence of using small sensor nodes.

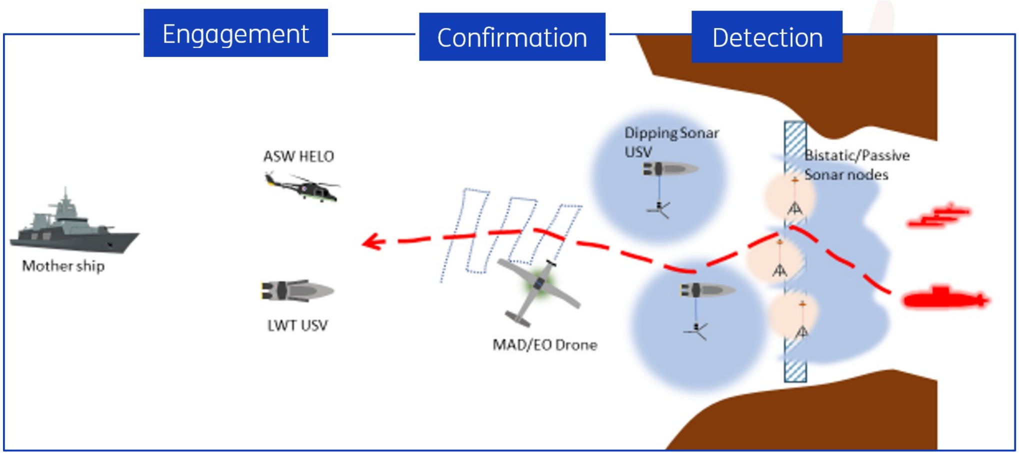

Fig. 1. Schematic overview of the envisaged engagement chain for an ASW barrier monitoring the passage of submarines through a chokepoint or near a harbour.

The passive nodes are typically being distributed in a line configuration on the seabed with several kilometres inter-node distance, together forming a virtual barrier. The active source(s) are represented by one or more dipping sonars operated from Unmanned Surface Vessels. The dipping sonars are stationary when active but are dynamic in nature to allow relocation when deemed necessary.

Since the passive nodes are not wired, they rely on acoustic underwater communications (UComms) to transfer their data. The typical low data throughput of UComms requires significant data reduction by the nodes. The nodes are equipped with processing hardware on which a high level of autonomy is required, covering the construction of sonar images from raw hydrophone data up to and including target detection, tracking and communication.

The development of an ASW barrier is a NATO initiative. As a result, emphasis is put on making all assets interoperable between nations, at all stages of the engagement chain. This means a high level of standardization is used and/or developed. Operations and communications follow existing or upcoming STANAGs as much as possible.

3. CONCEPT DEMONSTRATION

3.1. Test setup

In 2024 the Robotic Experimentation and Prototyping for Maritime Unmanned Systems (REPMUS) exercise, led by the Portuguese navy, was joined by The Netherlands. An experimental barrier was deployed and tested with partner nations Sweden, Germany, the United Kingdom, Norway and Finland. The setup (Fig. 2) consisted of an experimental dipping sonar (Fig. 3), launched from a RHIB, and passive NILUS bottom nodes [4] of the different nations. The civilian ship GeoSea served as Command, Control and Communications (C3) station. The SEMA AUV from RTSYS carrying an echo repeater was used as ASW test target.

Autonomous processing on the NILUS nodes delivered contact tracks that were encoded and transmitted acoustically to the RHIB. Results were forwarded to the C3 station where they were fused to create a georeferenced picture of contact tracks in the vicinity. These tracks were communicated to the Maritime Operations Centre (MOC) on shore, using the Collaborative Autonomy Tasking Layer (CATL) [5] over the C3MRE network of CMRE. CATL is an interoperability standard under development, that enables collaborative autonomy between unmanned systems of NATO countries. After reception at the MOC, the target confirmation process could be commenced.

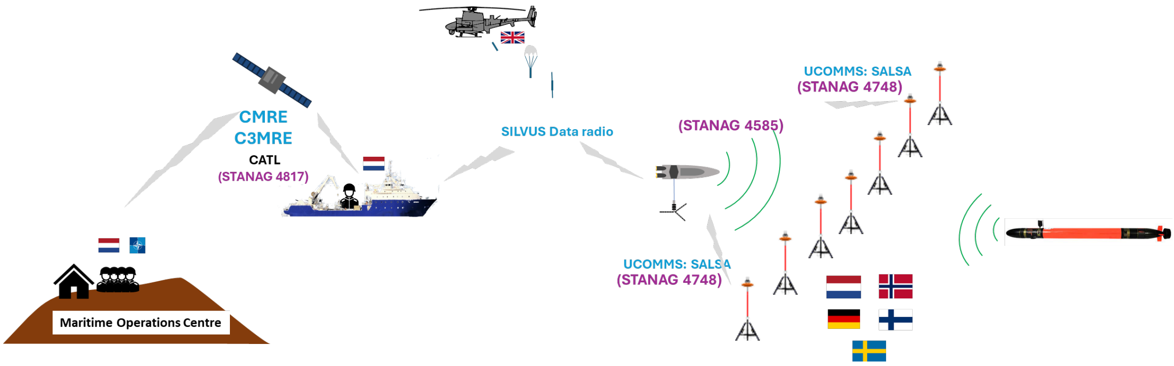

Fig. 2: Overview of deployed ASW barrier testbed at REPMUS '24.

Fig. 3: Left: TNO experimental dipping sonar, right: NILUS node. From [2].

3.2. Detection and tracking

An experimental dipping sonar transmitted Generalized Sinusoidal Frequency Modulated (GSFM) pulses [6] to allow robust, Doppler-sensitive detection of moving targets. Autonomous processing on both the dipping sonar and the bottom nodes converted raw hydrophone data into sonar images after which contact detection was performed (Fig. 4). Contact tracking on the nodes provided reduction of false alarms and target motion analysis. Tracking was done in range-doppler-SNR domain since no bearing information was available due to the use of only a single receiver on the nodes. Note that the detection ranges are relatively low, as a result of using low source levels on the dipping sonar. Operational detection distances will substantially increase when using source levels that are more realistic for ASW operations and when equipping the bottom nodes with an array of receivers.

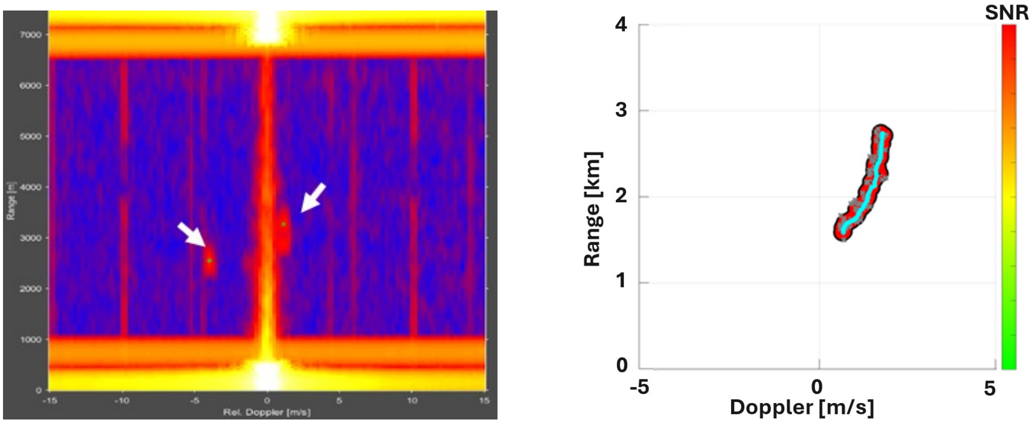

Fig. 4: Left: Range-doppler display of matched-filtered data of a single ping of the dipping sonar, including two detections [2]. Right: an example of a contact track constructed over the course of several pings.

3.3. Underwater acoustic communication

All bottom nodes were running the Smart Adaptive Long and Short-range underwater Acoustic Network (SALSA) protocol stack [7], together forming a communication network for transmitting and relaying tracking results to the gateway at the RHIB. Frequency Repetition Spread Spectrum (FRSS) [8] was used as physical layer protocol, allowing transmission of 256 bits per acoustic message of which 160 bits were available for contact track information. A dedicated encoding protocol allowed the efficient transmission of three contact tracks per message, leaving sufficient detail for proper fusion of node results at the surface. Fig. 5 shows an example of contact tracks on one of the nodes (left) and their decoded versions at the C3 station (right).

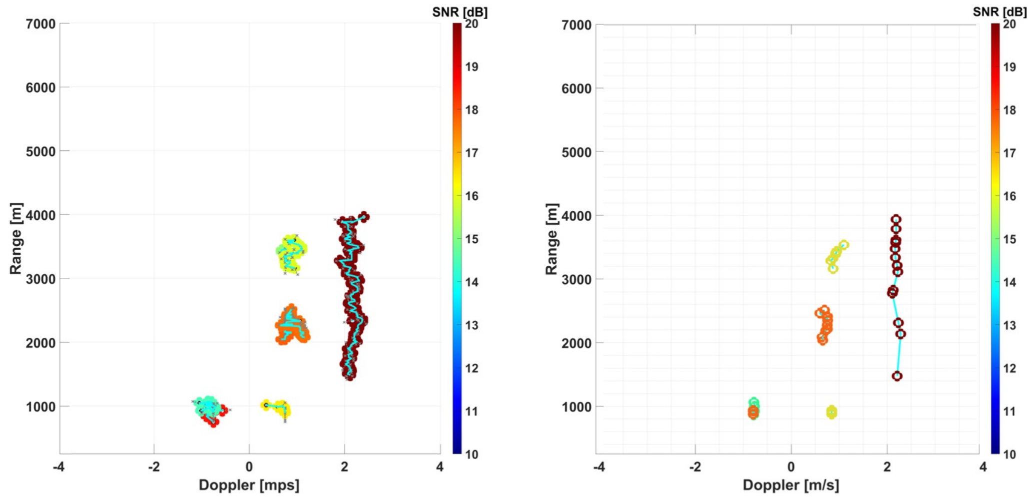

Fig. 5: Track communication protocol. Left: All range-doppler-SNR tracks at one of the bottom nodes built up over the course of 2 hours during one of the experiments. Right: The same tracks after encoding, acoustic communication and decoding at the C&C station, transmitted in three FRSS messages.

3.4. Track fusion

At the C3 station the tracks of all nodes were collected and fused to create a georeferenced picture of contacts in the vicinity. Using source and receiver positions, the contact tracks were converted to particles describing bistatic ellipses. Intersection points on these ellipses provided a georeferenced contact location. Aggregation of these points resulted in georeferenced contact tracks (Fig. 6). Since tracking on the nodes was performed in the range-doppler(-SNR) domain, three nodes with a target track are required to deliver a unique solution. The intended addition of bearing information will in principle require only a single node to provide a georeferenced contact position.

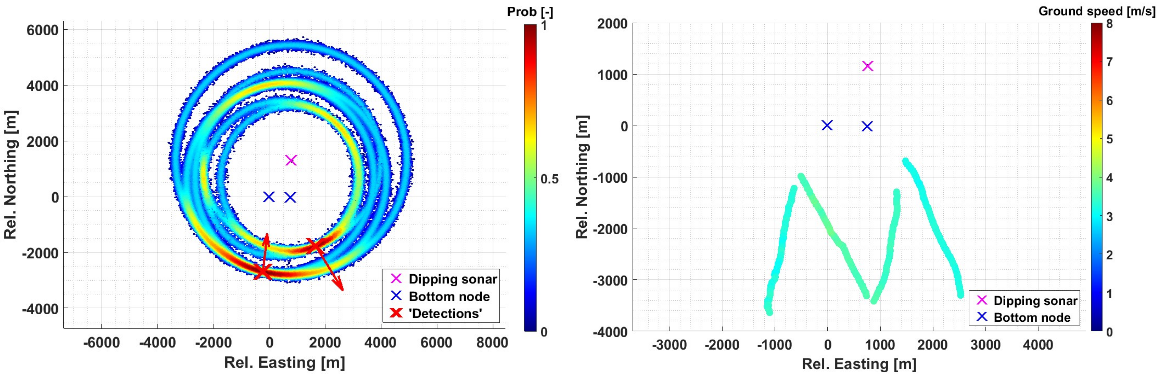

Fig. 6: Fusion process at the C3 station. Left: snapshot of particles describing bi-static ellipses from contact tracks of three assets at a single time instant. Intersection points (red crosses) lead to georeferenced contact positions. Right: aggregated contact positions resulting in georeferenced contact tracks.

SUMMARY AND DISCUSSION

In this paper, the results of a successful demonstration of a NATO ASW barrier were provided. The use of small, unmanned, low-cost systems and the emphasis on interoperability with other nations makes this solution scalable to larger scenarios. The developed autonomous processing capabilities on the nodes proves to deliver substantial data reduction and allows operating in communication-degraded circumstances. The high level of autonomy on all layers of operation complies with the demand for little to no operator involvement.

The current demonstration used bottom nodes as passive receive elements. To increase the range of opportunities in which the developed building blocks can be exploited, future work will focus on the augmentation of this system-of-systems with sonobuoys. At the same time, developments will focus on further reducing the amount of communication by the nodes and increasing area coverage by supporting the use of multiple dipping sonars in parallel.

4. ACKNOWLEDGEMENTS

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