Netcentric underwater warfare

the Remedy for 'Silent Subs'?

Although in most recent crises around the world it would appear from a superficial glance that there was no imminent underwater threat, a closer look shows differently. In the war on Iraq, for instance, a large allied effort was spent on eliminating the very real mine threat that endangered the supply of troops and goods to the harbour of Umm Qasr, even though a large proportion of the mines could be intercepted before they were deployed.

Introduction

Furthermore, the allied naval forces had a big concern about the Iranian Kilo class submarines that easily could have affected the operations. Although these submarines did not enter into the war this time, the threat that they could have done so was enough to force a large-scale effort on underwater surveillance.

Objective figures show clearly that, while the open-ocean Soviet submarine threat has diminished, the proliferation of diesel-electric and midget submarines to coastal states in unstable regions has drastically increased in recent times. Even if not all of these submarines are fully operational and state-of-the-art, the threat they pose is enormous and the required effort to eliminate this threat is disproportionally large. NATO navies, though well-prepared for Anti-Submarine Warfare (ASW) in the open ocean, hardly have effective means against the silent, small and elusive threat in coastal and shallow water areas. Therefore it is no wonder that quite a number of navies, among which the US Navy, have decided to increase their R&D efforts on shallow-water anti-submarine warfare.

Also in the Netherlands underwater warfare remains an important priority. In this article we will concentrate on the submarine threat in shallow water. We will discuss the necessary technological advances and the best operational concepts to tackle this threat. The proposed solution is not of the "measure on counter-measure" type as common in many arms races, but a fundamentally new way of deploying sensors in a *netcentric* configuration. This means that a large set of conventional and innovative sensors will share information via data links and together build up a complete picture of the underwater world.

Technological advances and novel concepts for underwater warfare

Since most present-day ASW capabilities originate from the Cold War era, they are primarily designed to counter large and noisy nuclear submarines in blue water scenarios. The shift to the acoustically much more complex and difficult coastal and littoral-water areas (brown water) and the use of smaller conventional submarines warrants drastic changes to the underwater sensors and the way they are used. The smaller and quieter coastal diesel-electric and midget submarines can only be detected in the noisy coastal environments by a low-frequency active sonar (LFAS) approach. It is therefore no surprise that many nations have decided to pro-

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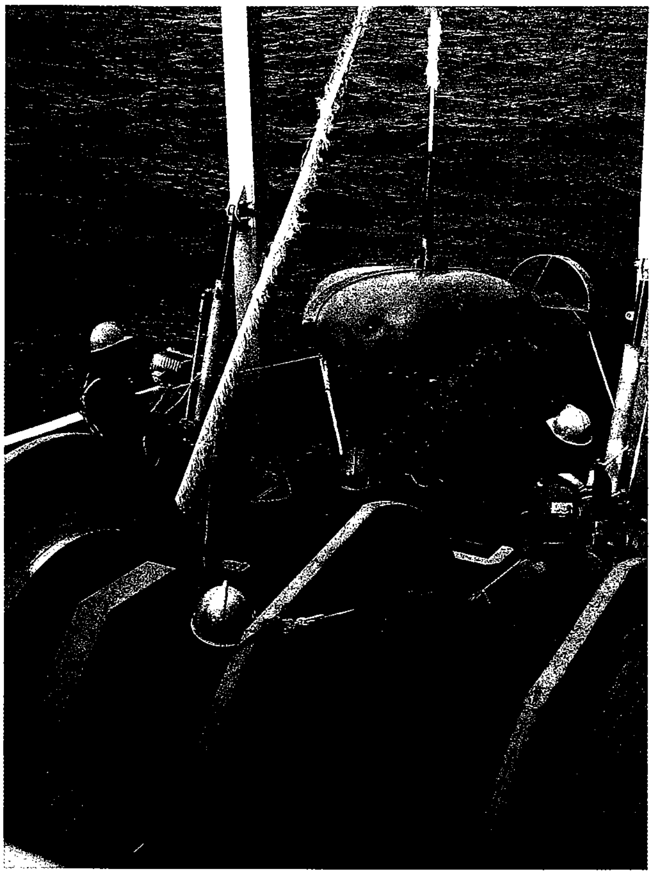
cure LFAS systems for their navies. Besides countries in the middle east (like Saudi Arabia) and Asia (like Singapore and Pakistan), examples within NATO are Norway (coming into service on the new frigates from 2005 onwards), the United Kingdom (sonar 2087, coming into service in 2006), France (on the new multi-mission frigates from 2008 onwards), Germany, and The Netherlands (procurement will start in 2010).

In this light, TNO-FEL, in cooperation with the Royal Netherlands Navy, has dedicated a large R&D effort on LFAS for a number of years. It started in the early nineties, when TNO conducted extensive deep-water trials with the experimental LFAS system "ALF", developed by TNO, achieving detection in the first and sometimes second convergence zone. Later research focussed on testing and further developing commercially available systems. Successful long-range detection in shallow water was achieved in trials carried out in 1998 with the Atlas Elektronik ACTAS system and the Thales Underwater Systems (TUS) CAPTAS system. In 1999 the first successful bi-static experiments were conducted with the TUS LFAS system, later sold to Saudi Arabia for their SAWARI frigates. These experiments were carried out in the acoustically very difficult area on the continental shelf break near La Coruña, North of Spain. Between 1999 and 2000 the compact multipurpose LFAS source, called SOCRATES, was subsequently developed and built in-house at TNO-FEL. This source combines a small size with a large flexibility and performance. In the period 2000-2003 we primarily experimented with a system consisting of the SOCRATES source and two CAPTAS triplet-array receivers, joined by France and Norway to execute bi-static experiments in littoral waters and even in fjords. Recently, in September 2003, a netcentric underwater-warfare trial was conducted with the NATO Undersea Research Centre in La Spezia, Italy. In this trial we operated with two state-of-the art LFAS systems and a submarine equipped with a towed array. In both controlled and free-play experiments long-range netcentric detections were achieved.



SOCRATES source ready for deployment. (FEL-TNO)

the proliferation of diesel-electric and midget submarines to coastal states in unstable regions has drastically increased

Early 2002, a large three-year contract-research program financed by TUS started. This so-called LFAS FUTURE program focuses on developing new additional LFAS signal-processing functionalities.

From these large theoretical and experimental efforts it followed that there is no simple solution for underwater warfare in coastal areas. It is clear that monostatic LFAS is already a revolutionary step forward compared to the current (cold-war era) operating sonars. In addition, a netcentric approach, using frigates with LFAS, helicopters with low-frequency dipping sonars, MPAs with sonobuoys and submerged submarines with towed arrays to establish jointly a common recognised underwater picture, will be the ultimate way forward to an adequate solution. In such a network all sensors at the network nodes need to be optimised for their individual performances, in order for the combined effort to give sensible results. Furthermore, spectacular advances in passive sonar are needed for submarines and other platforms that, for tactical reasons, need to remain covert. In the remainder of this article we will therefore first outline what can be done to further optimise and improve present-day LFAS systems, as the primary sensors in the network. Furthermore we will describe our netcentric underwater warfare effort, the associated problems and how to overcome them. We will end with a concluding summary.

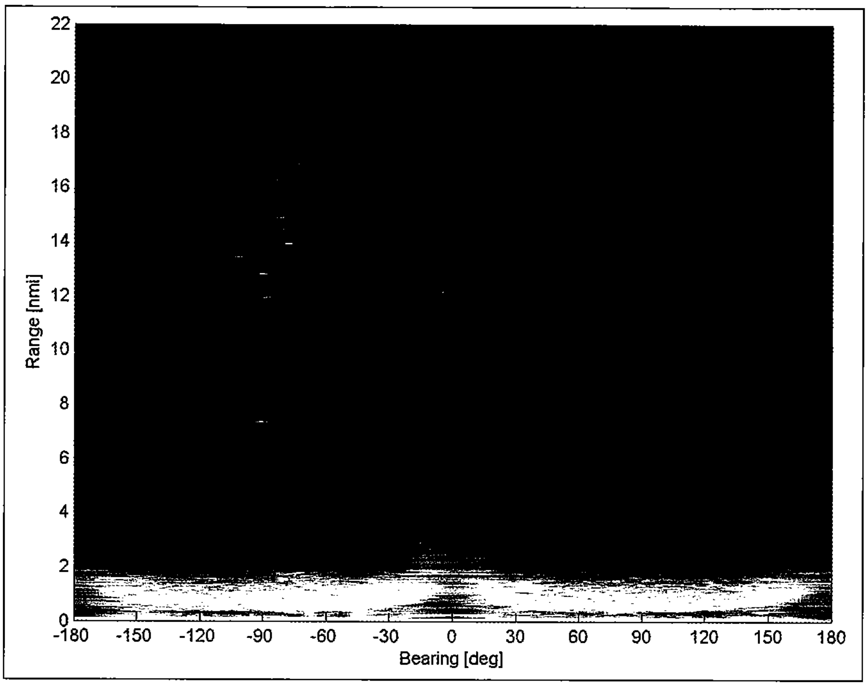
LFAS, the next generation ASW sensor

ASW sensors on board the current generation of frigates are Passive Towed-Array Sonars (PTAS) and Hull-Mounted Sonars (HMS). Both systems were designed during the Cold War for deep water and show significant shortfalls in shallow water ASW operations. The PTAS systems are dependent on emitted noise of the enemy target, of which the level has dropped over the last decades, while the background noise in new littoral operation areas has increased. The HMS systems are active and therefore independent on the target's noise. However, being mounted in the hull they operate in the surface layer and their transmitted sound of relatively high frequency propagates poorly and is often unable to penetrate into deeper layers, where submarines can easily hide. Both sensors are unable to detect a small and silent submarine in shallow water at the so-called torpedo range, i.e. the range at which the submarine can successfully launch a torpedo.

Low-frequency active sonar (LFAS) systems are the main candidates to replace current ASW sensors and to overcome this operational shortfall. LFAS systems consist of an active towed source and matching passive towed-array receiver. They combine the favourable properties of the current sensors. They are active systems, but can be deployed at variable depth, using low-frequency sound to minimise propagation loss.

Although the first LFAS systems are already operational, still much R&D effort is needed to improve the performance. In most operation areas performance is not limited by detection performance. The LFAS is designed such that the signal-to-noise ratio is mostly more than sufficient. However, the good detection performance also causes problems; an excessive false-alarm rate (up to hundreds per ping). Not only submarines induce echoes, but also many other objects on the sea floor or in the water column do: sea mounts, rocks, oil pipes, wrecks, containers and even schools of fish or whales.

spectacular advances in passive sonar are needed for submarines



A typical LFAS display in a shallow water environment with bearing on the horizontal axis, 0° being the sailing direction, and range in nautical miles on the vertical axis. In the forward direction noise from the tow ship is visible. On the port-side a coastal slope is inducing a lot of clutter. These bottom features give submarine like echoes. The target submarine is detected in the bearing −90° at a range of 7 nmi. Note the good port-starboard discrimination achieved by triplet processing. On the starboard-side the sea is empty apart from a merchant vessel in the bearing +50°. (FEL-TNO)

Much R&D effort therefore focuses on false-alarm reduction. An opening was provided by a break-through in transducer technology: the free-flooded ring (FFR). The ring transducer has two resonances and by filling up the gap between these, a wideband transducer is created. FFR transducers are the first to combine a large bandwidth of more than one octave with a high source level. The signal processing of wideband pulses provides lots of opportunities for false-alarm reduction, three of which are worked out below and are under special attention of TNO research:

- the use of wideband Doppler-sensitive pulses,
- target resolving power to enable object shape estimation,

- adaptation of the sonar to its acoustic environment.

The use of wideband Doppler-sensitive pulses has great operational benefits. The reverberation levels after Doppler processing are lower than for standard FM pulses, which improves the detection process. Once detected, the measured Doppler of the object gives a clear indication whether it is a moving or a stationary object.

Another way to exploit the large bandwidth is to resolve the detected objects. This provides insight into the shape of the object, which clearly helps to get rid off false alarms from bottom features. This method is even more effective if used in combination with sea charts, wreck databases and tracking algorithms.

Finally redundancy in bandwidth enables the selection of the most favourable subband. By means of acoustic performance modelling the acoustic background can be predicted. A software aid can then decide which subband is optimal for detection, i.e. where background levels are lowest. If modelling improves, the models can even predict clutter and provide area-dependent thresholds. Currently modelling performance is limited by the lack of knowledge of the necessary environmental input parameters. These parameters could be derived from databases, or via a through-the-sensor approach using inversion methods. This type of rapid environmental assessment (REA) techniques are still under development and will be increasingly important in future ASW operations.

As the LFAS has a towed receiver, the PTAS systems have become superfluous. The LFAS receiver (although often shorter and less adequately equipped for very low frequencies) can take over most of the remaining passive tasks of the PTAS systems. Note that passive operations will still be required; not all enemies are quiet and sometimes covertness is a tactical requirement. Furthermore, detection of small noisy targets as powerboats or torpedoes can best be done passively, although TNO-FEL and TUS are currently performing research to make active detection of small fast-moving targets, like torpedoes, with LFAS feasible.

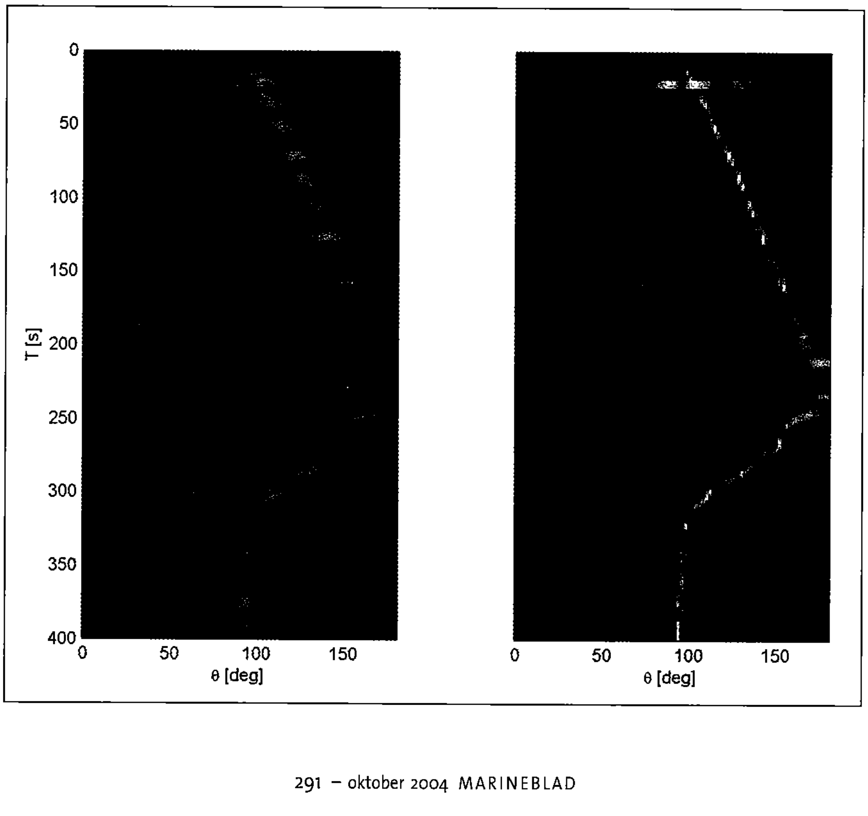
this sounds almost too good to be true

Passive acoustics is still of operational interest (do not forget that it is the main sensor on board submarines), but the sensor is getting more and more inadequate. It is therefore time for a quantum leap in passive sonar-signal processing. Fundamental research in this field mainly focuses on two topics: passive synthetic-aperture sonar and matched-field localisation.

The former is a technique to extend the array length artificially by making use of the motion of the sensor. This method increases bearing resolution, especially desired at low frequencies, and seems well-suited for application to the relatively short LFAS arrays. For example, an LFAS array processed with this technique should be able to detect the 50- or 60-Hz tonals of nuclear submarines, which is way out of range without synthetic-aperture processing.

The technique of matched-field localisation is an attempt to match a modelled signal with an actual received signal. Provided that the modelling is accurate enough, matched-field localisation can determine the target's range and depth. This sounds almost too good to be true, and indeed the method is still beyond cur-

Passive Synthetic Aperture Sonar techniques are applied to improve passive sonar array performance. The left-hand waterfall has been obtained using a conventional processor. The right-hand waterfall has been generated through Synthetic Aperture processing, yielding better localisation performance. (FEL-TNO)



rent capabilities. However, the use of REA to obtain sufficient environmental inputs for proper modelling offers possibilities. If we can make matched-field localisation work, preferably in combination with passive synthetic-aperture sonar, a target solution in range, bearing and depth is available. This accurate three-dimensional localisation could establish enough processing gain to achieve the desired quantum leap in passive performance.

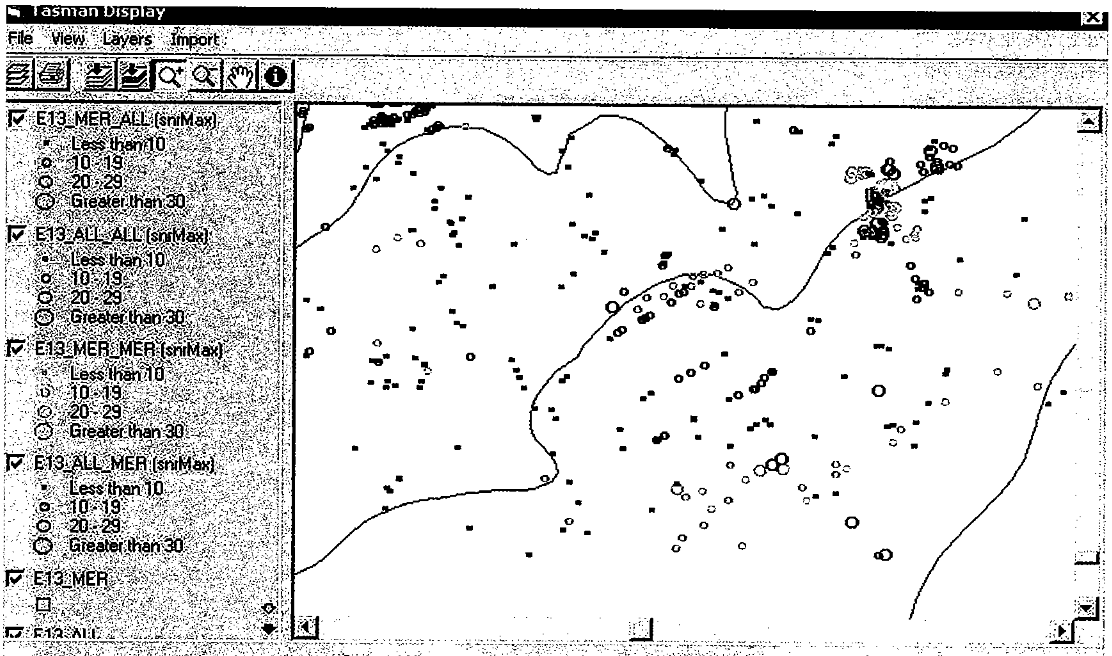
the potential benefits of a network of sensors are large

Netcentric underwater warfare

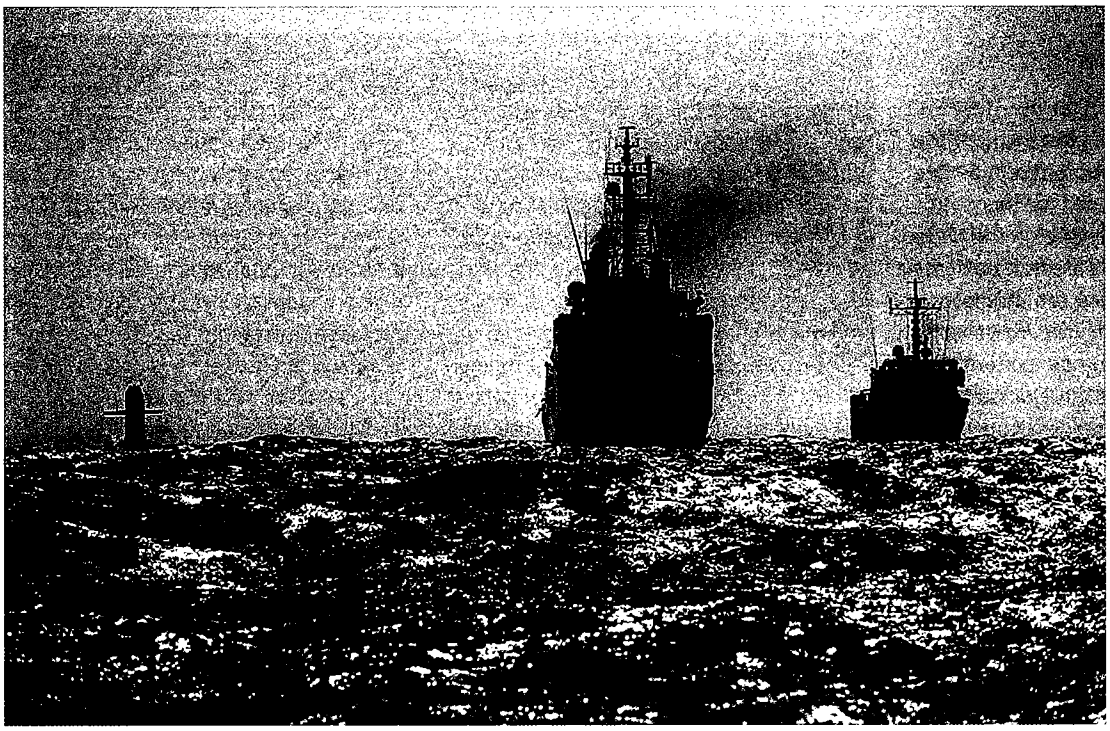
The previous discussions demonstrate that LFAS systems are nowadays the systems most capable to detect submarines, whether large or small, and to tackle their threat. The systems allow one to deploy at an optimal depth, based on in-situ measurements of the environmental conditions. The high power of FFR transducers often results in a high detection probability, though at the cost of a high false-alarm rate. Being the strength of these transducers, the high power also imposes a weakness: the system is vulnerable to hostile units as its transmissions can be heard to large distances. An enemy submarine will notice its presence and may adjust its strategy and tactics to this, hampering detection by either showing its least favourable aspect angle or lowering its Doppler speed. The obvious solution, to go passive, is no alternative as most submarines are too silent nowadays, as we have seen before.

To impose an enhanced threat to a possible target submarine, one or more passive systems can be positioned in the area to co-operate with an active sonar. These passive systems can be deployed on other platforms, on submarines, as passive sonobuoys (possibly dropped by a helicopter), or as moored receive arrays. In this way a network of distinct sensors is created. Although the active system will still be vulnerable by giving away its presence, the stand-off passive receivers in the network can remain covert and stay undetected by the threat submarine.

The potential benefits of a network of (underwater) sensors are large. First of all, having multiple sources and/or receivers, the area coverage and detection performance will increase. The more detection opportunities or nodes, the higher the overall detection probability. This increase in overall performance has been demonstrated several times, both via models and, more importantly, also in experimental situations. Secondly, combining multiple (independent) sensors, the high false-alarm rates in coastal waters will be



Example of netcentric data fusion. Identified contacts of multiple source-receiver nodes (characterised by the different 'greys' of the symbols) are gathered (in real-time) on a single geographic display. Depth contours help to classify some contacts as bathymetric features. (Picture provided by NATO Undersea Research Centre)



Three ships participating in NL/SACLANT Centre netcentric undersea warfare trial. (FEL-TNO)

reduced. By combining the recordings of multiple receivers, many false alarms are unlikely to occur in all of these, thereby offering a means to get rid off many of these spurious contacts. Thirdly, passive stand-off receivers offer the possibility to detect targets by observing them from a more favourable aspect angle, or measuring their non-zero Doppler, whereas the aware target aimed to show its least favourable aspect angle and/or zero Doppler to the active source.

While these netcentric underwater-warfare concepts offer a better theoretical performance, the actual increase in operational performance depends crucially on a perfect synergy between all nodes in the network. These should co-operate at a very high degree, both on a system level, a tactical level, and a data-sharing level, most likely supervised from one central control room.

At the system level, discussions are going on within NATO, to come to a set of basic system parameters. This set of parameters should allow systems of different countries (within NATO) to work together in a netcentric operation quite easily, without the need for expensive, time-consuming modifications.

At the tactical level, advanced models are needed to allow optimal deployment of all sensors in the network, and to minimise the searching time and maximise the detection performance for a given operation. Such models are being constructed presently by different R&D institutes. They often allow for a diverse suite of sensors, such as helicopters with dipping sonars, ASW frigates, submarines, and sonobuoys, and allow a comparison between the performance of the netcentric system and the individual single-sensor systems.

the need to combine and fuse the data from the different nodes in the network remains

Position information

An optimal co-operation between separate, distant, and possibly quite diverse, (sonar) systems also imposes huge demands on the individual systems, in terms of data processing, -interpretation, and -sharing. To allow reliable data processing, each passive receiver must have a real-time knowledge of the sonar transmissions by the source(s). Knowledge is needed of the exact transmitted waveform (length, bandwidth, etc.), but also the transmission time, and the exact location of the source. If this information is not available, the added value of the system drops enormously. Work done at TNO-FEL and by others demonstrates that position information is very important to do a proper fusion of the data of the different sensors. Consequently, much effort is spent to enhance this positional knowledge and make it available to all participating sensors. For surface ships, or surface buoys, most of the essential information can be sent via a direct radio link, if the different sensors are within each others' radio horizon, or via a satellite. However, for bottom-moored buoys and co-operative submarines, participating as passive receivers, such communications are impossible.

A promising solution is to use the ASW sonar itself to transmit pulses which have the relevant information (such as the source position) encoded in them. This encoding can be done either in the pulse used for detection and classification of the target, or in a dedicated communication pulse. Research, both theoretical and experimental, is going on currently at TNO-FEL to investigate these possibilities, and to determine the ranges of operation of this way of communication. Recently, during experiments with the NATO Underwater Research Centre, the feasibility of underwater-communication pulses has been demonstrated up to large distances.

Once all units and sensors have been deployed in an optimal configuration, and are aware of each others tactics and transmissions, the final step is to combine all information, gathered on the separate sensors, into a common underwater picture on the master unit. The ultimate aim will be that all units can see this picture, but the feasibility of this is questionable. However, the need to combine and fuse the data from the different nodes in the network remains. To solve this need is far from trivial, both on the technical level and on the algorithmic level. How to get all the relevant information at one point, and what information to gather? For covert systems it is undesirable to send much data by any means, as this makes them vulnerable. Here again, underwater communication may be one solution, as the (usually) wideband pulse is hidden in the background noise for observers who do not have any knowledge of the encoding scheme.

It is as yet almost impossible, and undesirable, to communicate *all* received data of e.g. a broadband sonar system to the central node of the network. Rather, one has to rely on only contact data or, for even lower rates, track data. The question whether fusion of contact data or fusion of track data is superior from a performance point of view, remains to be answered, and this topic is studied in many places around the world, including in The Netherlands. It is likely to depend on the variety in sensors and the expected sensitivity of these, but no unambiguous statement on this can be made yet.

Ingezonden mededeling

Nederland heeft weer een vliegende Catalina

Na vijf jaar hard werken heeft de volledig gereviseerde historische Consolidated PBY-5A Catalina met registratie PH-PBY (16-218) op 30 augustus op het Marinevliegkamp Valkenburg na een Roll-out en doop weer het luchtruim gekozen.

Emotioneel moment

De Catalina is Karel Doorman gedoopt door de weduwe (93 jaar) van de schout-bij-nacht. Zij werd daarbij geassisteerd door haar zoon Theo Doorman. Voor beiden was dit een emotioneel moment.

Na de Slag in de Javazee, waarbij schout-bij-nacht Karel Doorman en ongeveer 1.000 man marinepersoneel het leven hadden verloren en Nederlands Oost-Indië was gecapituleerd, zagen zij beiden kans om samen met andere KM-gezinnen met Catalina's en Dorniers te evacueren vanuit het voormalig Koninkrijksdeel.
Op 3 maart 1942 werd hun vluchtpoging wreed verstoord toen zij met negen MLD-vliegtuigen waren gelegen in de Roebuck baai nabij Broome aan de Noordkust van West-Australië. Op die ochtend werden zij aangevallen door Japanse Zero jagers waarbij alle MLD-vliegtuigen tot zinken werden gebracht en 42 mannen, vrouwen en kinderen het leven verloren. De weduwe van Karel Doorman en haar zoon wisten samen met de overgebleven gezinnen, en geholpen door marinepersoneel, door een brandende vuurzee het strand van Broome te bereiken.

Roll-out

Nadat de deuren van hangaar 6 door vrijwilligers van de Stichting Neptune Association (SNA) waren opengedraaid werd de Catalina, begeleid door de