FEATURES

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Taking guard: diver-detection sonars

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A new generation of sonar surveillance systems has been designed to provide early warning of diver intrusion

Over the past decade there has been an awakening across government and industry of the vulnerability of deployed maritime platforms (including warships and auxiliaries), coastal military installations (such as naval bases, weapon-handling facilities and fuelling stations) and critical civil/commercial infrastructures (ports, terminals, power stations, oil rigs and desalination plants) to asymmetric attack from terror groups and irregular combatants.

This has generated a flurry of activity among front-line operators, defence research laboratories and industry to devise ways and means to better protect the 'maritime flank'.

In the above-water domain, greater cognisance of threats such as suicide craft and infiltration teams have seen the introduction of layered anti-terror/force-protection (AT/FP) measures designed to detect, classify, identify, and, if necessary, neutralise hostile elements before they can reach their intended targets. These constructs typically combine networked surveillance sensors (principally radar and electro-optical/infrared) with agile and responsive AT/FP platforms (typically patrol craft or unmanned surface vehicles) and improved ship defences.

The provision of subsea surveillance around deployed high-value assets and critical infrastructures is an altogether less mature area, but one that is receiving increased attention as the threat from swimmer delivery vehicles (SDVs) and divers have become better understood. While combat frogmen are nothing new - the Italian Navy scored notable successes with underwater charioteers during the Second World War - it is only latterly that the threats their ilk pose has re-entered the consciousness of security planners.

One industry insider said: "There are billions of dollars worth of facilities and structures under or adjacent to the sea. Governments, and particularly the energy industry, are finally waking up to their vulnerability to attack."

He added: "Scuba training is relatively cheap and easily accessible. Even a single terrorist equipped with a limpet mine or IED [improvised explosive device] could wreak havoc, with huge financial, environmental and/or political consequences."

Active sonar - the transmission, reception and processing of pulses of acoustic energy - offers the only practical means of surveillance through the water column (sound waves have a low attenuation and long propagation distance in turbid harbour waters relative to other means of sensing). Indeed, the past five years have witnessed a significant increase in activity as a plethora of new sonar surveillance and alerting devices have been brought to market.

Two market niches have appeared: one for larger, multisensor diver-detection sonar (DDS) systems designed to watch over a relatively large area; and a second for more compact, lightweight and mobile devices better suited to confined areas or the protection of high-value vessels deployed into high-threat regions.

However, there are - in a technical sense - no easy routes to take when it comes to delivering the range and/or resolution required to provide adequate warning time to positively identify and respond to an approaching threat. Those engaged in the design and manufacture of DDS systems make no secret of the performance challenges posed by the low-signature target characteristics and challenging

environmental conditions encountered in harbours, ports and shallow coastal waters: a slow and 'stealthy' low-target echo strength diver using re-breather apparatus represents a very difficult sonar target; depth, bathymetry and variable sound profiles, can lead to problems such as reverberation, multipath reflections and poor range performance; and harbour traffic noise and maritime mammal activity can result in problems such as false alarms and missed detections.

Keeping a straight course

The challenge faced by the sonar and systems engineering community is, therefore, a difficult one: on the one hand to deliver robust and reliable early detection, auto-track formation and classification to allow for an effective response; and on the other to accurately discriminate targets from background noise so as to minimise the false-alarm rates and maintain user confidence while avoiding unnecessary investigation of spurious contacts. Just behind this are other key user requirements: a simple and intuitive user interface to enable operation by unskilled operators; outstanding availability, reliability and maintainability; and low through-life costs of ownership.

Accordingly, a range of proprietary DDS solutions have emerged onto the market in recent years. Some have attempted to re-engineer existing sonar devices; others have chosen to develop all-new systems, adopting innovative technology solutions and novel signal-processing techniques, tailored to the diver-detection task.

Israeli sonar, acoustics and systems house DSIT Solutions has adopted the latter course - and stands as one of the pioneers in the DDS marketplace through the development of its widely sold AquaShield DDS system.

Its origins lie in research, development and operational analysis performed by the company with the Israeli Navy and the Israeli Ministry of Defence back in 2004.

The company secured its first sale in 2007 to Naftoport Oil Company in Poland and has subsequently sold almost 30 systems in the Asia-Pacific, European and Mediterranean markets. DSIT's sales list principally comprises energy and other commercial customers, although it is widely understood that the company has also provided AquaShield to Israel and other navies for harbour-security applications.

AquaShield comprises a PC-based control and display unit connected to a number of sonar nodes positioned on the seabed, or attached to a pierhead, to maximise coverage. According to DSIT, its DDS solution is the only system available that is able to reliably achieve long-range detection (up to 700 m) of closed-breather divers with a minimal false-alarm rate in conditions of high noise and reverberation. The company also asserts that the superior range performance delivered by each node translates into a requirement for fewer nodes and, hence, lower costs of ownership.

The long-range performance of the AquaShield DDS is attributed to a relatively low centre operating frequency (60 kHz) and commensurately larger arrays, and to the implementation of extremely low-noise electronics and advanced signal-processing algorithms for automatic detection, tracking and classification. The company indicates that the AquaShield is designed for operator-free use - that means the system is fully automatic requiring the intervention of security personnel only following alarm.

Performance features

The system offers anti-reverberation features that include a very narrow horizontal and vertical beamwidth; coherent processing; coded pulses; proprietary signal-processing algorithms. An embedded sonar performance prediction-model support function calculates the expected detection range.

AquaShield's omnidirectional transmit array incorporates 32 transducer elements, while each 125 cm horizontal receive array incorporates 96 pairs of hydrophone elements (three alternative transmit/receive array configurations are advertised covering 360-, 240- and 120- degree sectors). Electronics components can be packaged for above-water or submerged siting. The latter is typically chosen for seabed installations, while the former are usually associated with pier installations.

DSIT says that AquaShield has achieved detection ranges of up to 700 m against a closed-breather diver, and detections at 1,000 m against a diver using an open-breather apparatus, increasing to 1,500 m for a swimmer delivery vehicle (SDV). The company points out that the system is able to monitor both

the near and far fields, arguing that it is classification range and response time (with a 10-minute minimum threshold), rather than outright detection range, that really matters.

The company adds that the classification performance offered by AquaShield is achieved through algorithms that are based on advanced pattern-processing techniques designed to differentiate valid targets from noise and fish, and to distinguish between different target types (surface swimmers, divers with closed-circuit breathing systems, divers with open-circuit breathing systems, SDVs and surface craft). According to DSIT, the company has conducted hundreds of sea trials at various locations around the world, in different sea conditions and with all types of targets.

Acoustic raw data from these trials, as well as from deployed operational systems, is recorded and analysed to improve the signal-processing algorithms. This is a continuous effort that provides ongoing system improvement through the addition of new advanced algorithms.

AquaShield is able to automatically track more than 1,000 simultaneous contacts. Track data is overlaid onto a synthetic map display and presented on a standard PC-based console. A variety of display formats and range scales are available to the customer. Specific display features include scan-to-scan integration; up to four zoom areas to enable investigation of specific areas of interest or activity; suppression zones; and automatic target classification (an alarm being activated when a contact is identified by the system as a threat).

To address the market for more compact and portable DDS installations, DSIT is officially launching a smaller derivative system, known as PointShield, operating at 120 kHz and designed for short- to medium-range applications (such as a canal, a section of river, a water intake channel or a confined area). The company asserts that the PointShield offers the same features and benefits of its bigger brother - the AquaShield - at shorter ranges. Several PointShield systems were purchased and installed earlier this year in an unspecified Asian country.

This is a market segment where UK-based Sonardyne has achieved success with its Sentinel IDS marine intruder-detection sonar, a product described by its manufacturer as "a third-generation intruder-detection sonar designed to counter the threat of underwater attacks against ships, harbours, coastal industrial installations and offshore oil platforms". Launched in 2007, with more than 20 systems sold to date to customers in Africa, Asia, Europe, the Middle East and the US for a diverse range of maritime security applications, it melds the company's expertise in acoustic navigation, positioning and communications with product-specific engineering investment.

With a sonar head 440 mm high and 330 mm in diameter, and weighing less than 35 kg in air, the Sentinel IDS sensor has been designed to be considerably smaller than competing systems while still providing full 360-degree coverage. According to Sonardyne, the compact size of the sonar head "makes it ideal for expeditionary operations as it is capable of being easily palletised and rapidly deployed". The company added: "The system can be mounted in many different ways, including suspension by its own cable, pole mounted or on the seabed."

Acknowledging that the reliable detection of underwater targets and their discrimination from marine mammals is "a notoriously difficult problem", Sonardyne said that Sentinel IDS addresses this challenge by bringing together advanced sonar technology, commercial off-the-shelf-based processing units and automated detection, classification and tracking software. "The result," the company adds, "is a system that can function in a wide a range of acoustically complex subsea environments and ensure that only genuine threats are highlighted."

Low-frequency solution

Sonardyne selected a centre frequency of 70 kHz for Sentinel IDS, the company arguing that while many competing systems operate at higher frequencies, the adoption of a lower source level reflects its own system modelling and real-world experience. Offering a full 360 degrees of acoustic coverage, the system can be deployed to a depth of 50 m and is able to achieve detection ranges out to 900 m.

A Sentinel IDS command station can manage up to 10 sensor heads to provide wide area coverage. Each sonar head houses the electronics to control the transmitters and digitise and multiplex the received signals from the transducers. Multiplexed data is then transmitted to the topside equipment via a copper-based cable for cable lengths up to 100 m, or via a fibre-optic cable for longer lengths.

A single sonar head has eight separate 45-degree transmit sectors, each of which is individually addressable so as to allow any segment to be disabled to reduce nuisance acoustic returns from nearby objects such as harbour walls or jetties. The transmitters themselves are fully programmable and supplied with a number of frequency modulated Doppler-tolerant pulses that can be selected via the Sentinel IDS system configuration file.

The compact 1:3 piezo-composite transducer array has 128 separately wired elements, which are used to form 256 equally spaced receive beams, each with a 1.4-degree horizontal beam width. Software further interpolates these beams to provide highly accurate bearing estimation for the target.

The sonar tactical picture is presented on a PC-based command workstation. This shows the sonar data, track data and alerts overlaid on an electronic chart display; if multiple sonar heads are deployed, these are interfaced to the command workstation via an Ethernet local area network. Pulse compression, beam forming and automatic detection and tracking are carried out using two high-performance PCs installed in a rugged case (which also contains the power distribution unit for the sonar head).

In early 2008 the US Naval Sea Systems Command selected Sonardyne to supply multiple Sentinel sonar heads for the new Integrated Swimmer Defence System led by the Program Executive Office, Littoral Mine Warfare. In addition to the equipment provision, Sonardyne was also contracted for services associated with the integration and deployment of Sentinel systems as part of an expeditionary warfare requirement. The contracts, valued in excess of USD1 million, followed trials in October 2007 when the Sentinel IDS was trialled by the US Navy (USN) for four days at the US Naval Underwater Warfare Center, Newport, Rhode Island.

Further sales have followed. In September 2008 Sonardyne announced that a Sentinel IDS system had been sold "to the unnamed owner of a prominent superyacht", and in April 2009 the company revealed that the Slovenian Navy has taken delivery of a further system to protect key installations in the northern Adriatic Sea. The latter contract also included the provision of the new Sonardyne underwater loud hailer, called Scylla, which allows users to broadcast underwater warning messages to deter intruders once detected. Further orders have followed from China, the US and an EU research consortium.

Complex acoustics

Another UK-based company pursuing business in the undersea security market is Atlas Elektronik UK which, since the acquisition of QinetiQ's underwater business in 2009, possesses the Cerberus DDS in its product portfolio. Using a high-resolution 100 kHz wideband active-search sonar and a 1-3 piezo-composite 360-degree transducer array, the system features multiple-search arrays enclosed within a distinctive egg-shaped glass-fibre fairing. The complete unit is 1.2 m high, 0.7 m in diameter and weighs 45kg in water.

Cerberus leverages wideband sonar-processing technology culled from the UK Ministry of Defence's applied research programme and in use with the Sonar 2193 minehunting sonar. These techniques are claimed to overcome the complex acoustics encountered in harbour environments, offering sufficiently fine resolution to be able to classify the target and discriminate between a diver and a marine mammal such as a dolphin. In-water tests have shown the echo structure to be detailed enough to show the recognisable structure of a diver's chest cavity at a distance of over 400 m.

By using advanced sonar-processing techniques in conjunction with a database of known target signatures, the potential threat can be rapidly assessed and classified, thereby minimising false alarms and providing the maximum response time for security forces or devices. Maximum detection range is in the region of 800 m.

Cerberus is described as a self-contained DDS system that is easy to deploy and maintain. It can be used as a single unit to provide area protection or in greater numbers to form a security perimeter, with each unit acting as a node in a wider network.

The sonar arrays and signal-processing electronics contained within the 'egg' are linked by cable to a control station.

Digitised data is streamed back through a fibre-optic connecting cable to the processing platform on shore, where sophisticated algorithms identify potential threats by analysing direction, speed and behaviour patterns.

The processing system runs on a standard PC server, generating an image that can then be analysed by an operator. Cerberus can be operated independently or, alternatively, can be interfaced into an existing or additional surface surveillance security system or ship-command system, overlaying target classification and track and threat-assessment data.

A PC-based control unit, linked via cable into any number of sensor 'eggs', is situated in a host ship or shore station. Designed around a Windows graphical user interface, software-based functionality provides for fully automatic audio and visual alerts, location confirmation and multiple target tracking of more than 50 simultaneous contacts. Coupled with this is a manual capability to interrogate, process and display 'zoom' data in fine detail as required.

Data displayed in an adjacent window provides target co-ordinates, the speed of target, its heading, an assigned track number, the age of the track and the number of track updates, together with relative range and bearing from the sonar head itself. An alert indicator shows green, orange or red according to the threat status.

Building on the success of the SM 2000 underwater surveillance, advanced diver- and swimmer-detection sonar system, in excess of 30 examples of which are deployed for diver-detection applications, Kongsberg Maritime (through its Kongsberg Mesotech subsidiary) is marketing the derivative DDS 9000 multibeam sonar series. This new line builds on the heritage of the proven SM 2000 (which forms an intrinsic part of the USN's Integrated Anti-swimmer System for high-value asset protection), but introduces a range of updates to improve operational performance.

Homeland security arena

Kongsberg claims that the DDS 9000 is the first COTS-based DDS "to break through the Department of Homeland Security's low-cost goal of less than USD100,000 per 1,000 ft of protected shoreline", adding that its product "provides increased functionality, is easier to use, and is one third the weight of competitive 360-degree systems".

Compared with the earlier SM 2000 series, the DDS 9000 employs a much wider bandwidth and introduces pulse compression to improve range performance. Furthermore, sensors in every DDS 9000 series sonar head compensate for changes in pitch, roll, or bearing, ensuring the most accurate target position possible.

Based on analysis of market requirements, Kongsberg has specified two variants: the DDS 9000 covering a horizontal arc of 200 degrees; and the DDS 9001 providing full 360-degree coverage. With sonar heads weighing less than 90 kg, the DDS 9000 and DDS 9001 can be easily deployed by a small crew in less than one hour.

The tactical processor and tactical display run Kongsberg's Defender II software. This provides functionality for unattended operation with automatic alerts; automatic tracking of multiple sonar targets; automatic track classification; geo-coded track data for co-ordinated threat response; exclusion zones to eliminate high- noise areas, reducing false alarms; and chart overlays to aid situational awareness.

Regarding the sensor head, each DDS 9000 sensor node has 256 beams with a beamwidth of 1.5 degrees, the narrow beams allowing for discrimination of very small targets such as divers. The system is claimed to have a maximum range of 1,000 m with detection of diver-like targets at ranges in excess of 600 m. The sonar processor also uses a rugged rack-mountable computer chassis.

A tactical display showing Sentinel IDS sonar information overlaid onto a commercial geo-mapping product. (Sonadyne)
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