The Inescapable Net

Unmanned Systems in Anti-Submarine Warfare

Parliamentary Briefings on Trident Renewal
Briefing No.1
March 2016

by David Hambling

Introduction

Parliament is due to vote on the UK's nuclear posture and the Trident renewal programme sometime in 2016. The debate is often framed as a question of strategy when facing adversaries: do we take a robust and assertive approach that faces them down, or do we prioritise international collaboration in climbing down the nuclear ladder? But this masks other critical questions, not least whether the nuclear postures we choose actually work as intended (in deterring aggression). The first in our 2016 series, this briefing deals with one particular threat to the utility of the Trident system: emerging technologies that could in the not-too distant future render the oceans effectively transparent and a submarine-based deterrent irrelevant before the new submarines are even deployed.

Paul Ingram, BASIC Executive Director

Wave Glider with powerful sensors, and with surface board providing continuous power and communications

This document uses open sources to explore how small drone technology will impact the future detection and tracking of submarines. The availability in large numbers of low-cost unmanned platforms, known as unmanned vehicles or drones, equipped with sophisticated sensors and able to operate in swarms, is likely to be highly disruptive to naval operations over the next decade, particularly those dependent upon stealth. The drones involved include unmanned aerial vehicles (UAVs), Unmanned Underwater vehicles (UUV) and Unmanned surface vehicles (USV).

In the past, antisubmarine warfare (ASW) has been carried out by a small number of highly capable ships and manned aircraft. Their task has been like that of a handful of police looking for a fugitive in a vast wilderness. Lacking the manpower to cover the whole area, they have to concentrate their forces on the most likely paths and hideouts, and hope for a lucky break. With the advent of cheap drones, the police are joined by thousands more searchers, who are less well-equipped but have the numbers to walk shoulder to shoulder and sweep the entire area. Escape becomes impossible.

Submarine developers aim to reduce the signature of ballistic missile submarines (SSBNs) so that they can remain undetected.

But the laws of physics – not to say common sense – suggest that a boat five hundred feet long and weighing sixteen thousand tons, carrying an operational nuclear reactor, cannot be made to disappear utterly at close range. Small unmanned platforms can carry many types of sensors – active and passive sonar, magnetic anomaly detectors, wake detection LIDAR, thermal sensors, laser-based optical sensors capable of piercing seawater and others. A submarine which can be seen by any one of these will cease to be invisible. A submarine whose location is exposed is highly vulnerable to instant attack. If submarines are easily detectable, they lose all their advantages as strategic weapons platforms.

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About the author:

David Hambling is a freelance journalist and author, with a focus on evolving military technologies. He writes for New Scientist, WIRED, the Guardian, the Economist and various other publications. His recent book, Swarm Troopers (2015), charts the revolutionary impact the recent emergence of cutting-edge drones and related technologies is having on outcomes on the battlefield.

Part 1: UAVs – Rapid Ascent of Small Drones

The development of drones for ASW is likely to mirror their rise as tactical scouts on land. In 2003, the US Army tested a small number of hand-launched AeroVironment Raven drones.[1] Now they have some ten thousand drones, of which nine thousand are Ravens and close relatives made by AeroVironment.[2]

The utility of such drones is obvious: a soldier can launch one and get real-time video imagery from several miles away without exposing themselves to enemy fire. Drones can carry out perimeter patrols, locate enemy snipers and mortar teams, spot insurgents placing IEDs, or go ahead of convoys to prevent ambushes. A force with these drones can see the enemy's strength and disposition without ever being seen, and can precisely direct artillery or airstrikes on to enemy positions from long range.

Such small scout drones are proliferating, and are being joined by armed versions such as the US Switchblade and Israeli Hero-30 equipped with explosive warheads.[3] These can carry out precision attacks from a range of miles and are likely to have a disruptive effect on ground warfare.

Their success has been greatly assisted by the rapid evolution of sensors. Advances in technology have delivered sensors with steady improvements in "Size, Weight and Power" (SWaP) which are also getting cheaper. In the consumer field video cameras have changed from brick-sized analog devices recording on tape to button-like digital units built into smartphones. Similar advances have taken place in thermal imagers and radar.

In 1998 the smallest synthetic aperture radar (SAR) – a type which provides a video-like image through dust, smoke and darkness – weighed some two hundred kilos. Sandia National Laboratories managed to reduce this to under sixty kilos to fit on the new Predator drone.[4] By 2015 there was 'Nano-SAR' for drones weighing less than one kilogram.[5]

LIDAR, laser-based radar used for generating detailed 3D maps, has shrunk similarly. Velodyne now market a puck-like LIDAR unit for small drones weighing little more than half a kilo.[6] Much smaller units are already in prospect.

It is hard to overstate how rapidly electronics are evolving compared to the usual extended generation time of military hardware. Perhaps one of the most eye-opening facts is that the US's state-of the-art F-22 Raptor aircraft has data processing based on 1990's-era Intel 80960 processors.[7]

Israeli soldier launches Hero attack drone

These crunch numbers at about 9 million instructions per second; the iPhone 6 can execute 20 billion instructions per second, making it over two thousand times faster.[8]

The Trident Successor submarine is designed and will be constructed using modern electronics from today, will come into service in the 2030s and will be expected to patrol into the 2060/70s. The electronics of twenty years' time will be vastly more powerful than anything that exist today. This will have a direct impact on the ASW hunting the Successor, which relies heavily on signal processing.

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At the same time, the rapid rise of the consumer drone market has highlighted the fact that capable drones do not need to be expensive. While most small military drones still cost tens of thousands of pounds, a study by US think-tank MITRE has produced military-grade drones for less than a thousand pounds each by using commercial, off-the-shelf components and the Android operating system rather than bespoke military electronics and software.[9] This approach is now being taken up by the US Defense Department in their work on autonomous swarming robots.[10]

There is now considerable interest in harnessing such developments to produce swarms of drones operating together. The US Navy's Low-Cost UAV Swarming Technology (LOCUST) program aims to have thirty drones flying together without having to be individually controlled by summer 2016.[11] Such swarms are capable of searching large areas autonomously, making them well suited for ASW operations.

Small Drones At Sea


Coyote aerial drone with launch aircraft, able to carry critical sensors

Scenario 1: A Pack of Coyotes

A Boeing P-8A Poseidon is hunting a Russian submarine in the North Atlantic. A fleeting contact was reported some hours earlier, but the quarry has now disappeared and could be anywhere in hundreds of square miles of dark ocean depths. But the Poseidon, a modified Boeing 737, has a new way of lighting up that darkness.

As the plane flies over the submarine's projected course, there are a series of dull thumps as tubes on the Poseidon's underside eject cylindrical objects on parachutes. Once they have slowed down, the cylinders drop free of their parachutes, unfold their wings and start up their propellers. These are Coyote drones.

The drones drop to low level, and each starts flying a search pattern over its assigned area. They are fitted with **Magnetic Anomaly Detectors** (MAD), sensors able to detect a submerged submarine.

As more and more Coyotes are released, the data they send back is monitored by submarine hunters on the Poseidon. The blank spots on the map are gradually filled in, and within two hours the submarine is unmasked. More Coyotes are dropped to keep following the submarine; now that it has been found it will not easily be lost again.

MAD have been used for submarine detection since WWII. They have largely been eclipsed by sonar because of their limited range, which is of the order of hundreds of metres. A single aircraft can only search a narrow strip of ocean, and MAD is used mainly to confirm other means of location. It is still highly relevant though; the most conspicuous feature of the China's new Shaanxi Y-8Q submarine hunter is a seven-metre-long 'stinger' on the tail housing an MAD.[12] The US P-8A Poseidon does not include a MAD, although there is one on the version of the pane supplied to India. Instead, it will rely on remote MAD carried by drones.

In January 2015, BAE Systems was awarded an $8.9 million contract to provide a High Altitude ASW Unmanned Targeting Air System (HAASW UTAS) for the Poseidon.[13] This will use a MAD, along with associated software, carried by a drone launched from the aircraft.

> *"Thirty to forty MAD UAV platforms, operating on a co-operative behaviour mode, could potentially patrol 2500 km² of ocean with a high probability of detecting any submarine in the box and a low probability of false alarm,"*[14]

These drones will be small, deploying compact, sensitive, miniature MAD sensors based on an Atomic Vapour Magnetometer, under development by the US Navy.[15] In the longer term, a type of magnetometer called a SQUID – "Superconducting Quantum Interference Devices" – is likely to revolutionise the field. SQUIDs are extremely sensitive and are used medically to measure the tiny magnetic fields generated by the brain. In the past SQUIDs have been difficult to use in the field because of the need for cooling with liquid nitrogen, but micro-cryogenic coolers have recently become available so that a SQUID-based sensor could go anywhere. Future SQUID-based MAD will have much longer range than existing MAD.[16]

Nor will such drones be limited to MAD sensors. One of the features of the US Army's Raven drone is the 'plug and play' payload section which allows the camera unit to be swapped out for a thermal imager or other sensor in seconds. An ASW drone could use wake-detection radar or any other device as it becomes available.

As for the drones themselves, UAVs capable of launch from ASW aircraft are already in service. These include the Coyote, developed under the aegis of the US Office of Naval Research.[17] Coyote is fired from the tubes normally used to drop sonar buoys; it is a metre long and currently has an endurance of ninety minutes on battery power. The developers, Advanced Ceramics Research, were acquired by BAE Systems in 2009 and renamed Sensitel.

Coyote is currently used by the US National Oceanic and Atmospheric Administration, which flies P-3 Orion aircraft on its Hurricane Hunter missions.[18] Coyotes can be launched and flown into the heart of a hurricane, gathering data from locations unsafe for manned aircraft. They can measure water temperature with thermal sensors, as well as wind speed, pressure and other variables.

In January 2016, a Coyote successfully sent back data to its launch aircraft from fifty miles away. This demonstrates the effectiveness of small drones as air-launched remote sensors.

At around $15,000 apiece, the entire swarm of Coyotes costs less than one missile.

The Coyote is also used for the US Navy's LOCUST swarming drone project.[19] At around $15,000 apiece, the entire swarm of Coyotes costs less than one missile. They can be recovered and re-used, but even at this price they are considered an expendable asset.

The pieces are all falling into place: MAD suitable for small drones, drones suitable for long-range ASW, and the swarming software to control them are all available or in advanced stages of development. Their capabilities are improving month by month.

The Future Of Submarine Hunting Drones

While Coyote already demonstrates the potential of sub-hunting drones, it is limited by a mission time of only ninety minutes. Fuel cell technology might increase this by a factor of five in the near future, but other technology is emerging to increase the duration of small drone flights indefinitely.

Some small drones (e.g. Solar Puma, Silent Falcon) already have solar power assistance. Arrays of solar cells on their wings provide power, in some cases enough not only keep the drone flying but also to charge the batteries so it can keep flying through the hours of darkness. The AtlantikSolar drone has flown for more than eighty hours, showing it can go through multiple day/night cycles.[20]

Another approach is to borrow a soaring technique from nature. Albatrosses and other ocean birds are capable of flying thousands of miles with minimal effort by means of 'dynamic soaring'. This uses wind shear, the difference between the speed of the wind at sea level and at higher altitudes. The bird (or drone) turns into the wind, gains altitude and then glides downwards again, repeating the same process over and over. Studies suggest a dynamic soaring drone could fly at a steady 100 mph indefinitely without expending fuel.[21]

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In practice though, a drone does not need to stay airborne permanently. It can simply land on the water, and the technology of drone seaplanes is well-established. The US Navy even has a development project known as Flimmer, a small aerial drone which can enter the water and operate as a submarine -- with ASW being one of the proposed applications.[22] Test video shows the Flimmer's first flights, and the developers explicitly suggest that it may be an alternative to the traditional sonar buoys unable reposition themselves.

Another advanced concept in this area is the US Navy's innovative Sail-A-Plane.[23] This project, completed in 2006, was a drone which could land on the water and rotate its wings upwards to become sails. Solar cells would recharge the Sail-A-Plane while it was on the water (it might also harness wave power), and it could then take off again. The project was shelved after completion and several successful flights, but Sail-A-Plane demonstrates the possibility of unmanned craft carrying out missions of unlimited duration at sea. Fleets of such drones could be deployed in likely areas, ready take off and start searching at short notice.

Part 2: UUVs – Underwater Gliders

Scenario 2: Forever Patrol

It is yet another sunny day on the featureless Pacific, somewhere between Hawaii and the Aleutian Islands. Far from the shipping lanes, there is only one tiny craft visible. It looks like a surfboard covered in black solar cells, and it heads slowly but purposefully along, endlessly patrolling its assigned route.

Viewed from under the water, the surfboard is revealed to be attached to a glider unit by a tether, a glider towing a long sonar array. Wavepower provides propulsion, and solar power the electricity for the sonar. At intervals the small robot receives communication pings from other sentinels, some of them on the water and some underneath it. Occasionally it connects via satellite to send back data, to confirm that its systems are functioning, and to download software updates.

The sentinel is tireless, unsleeping and unblinking. When after several months of inactivity, the sonar suddenly picks up a large, moving object, it responds instantly.

Wave Glider surf board with solar power and communications, attached to drone below the surface

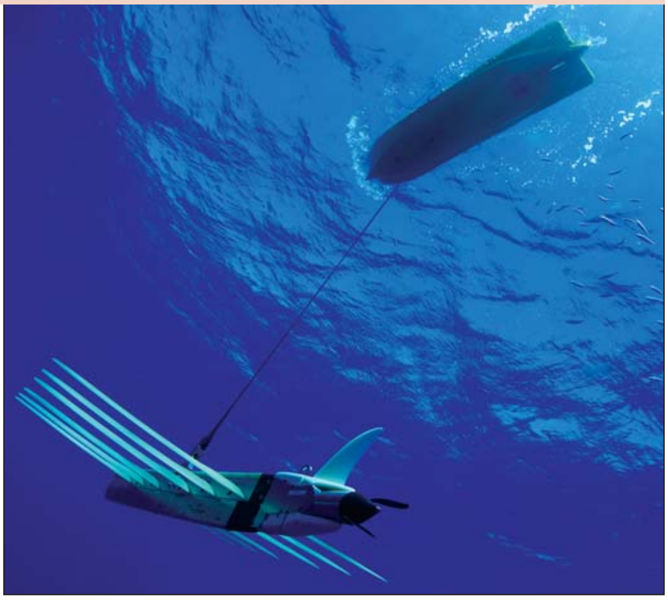
The sonar data is filtered, analysed and classified. Sophisticated algorithms confirm that this is not a false alarm, and the data is compressed and sent to the satellite in a steady stream for as long as the contact lasts.

The Russian submarine glides by underneath. Its crew are unaware that for several days their every move has been tracked by hundreds of the silent sentinels, each watching the submarine pass through its own area before it is handed on to the next.

Over the past twenty years a new type of **unmanned underwater vehicle** has been transforming underwater research. Unlike other UUVs which are typically tethered and have a very short range, underwater gliders can roam over long distances for months at a time.[24] They are typically a couple of metres long, weigh about fifty kilos, and look like small torpedoes with wings.

Rather than propellers, gliders have a buoyancy engine. This pumps a small quantity of oil from an external bladder to an internal one, changing the density of the glider so it starts to descend. As it falls, it glides on a shallow trajectory, reaching a speed of about half a knot. After descending several hundred metres, and travelling a few kilometres, the glider pumps the oil the other way and starts to ascend, gliding upwards at the same leisurely speed. It is a slow but frugal form of travel with a tiny power requirement. In 2009 the Scarlet Knight glider operated by Rutgers University completed an Atlantic crossing in seven months on one battery charge.[25]

Gliders are ideal for research tasks requiring long endurance or hazardous conditions. Gliders helped track the Deepwater Horizon oil spill, and measured radiation levels around Fukushima.



Wave Glider drone from below, packed with extremely sensitive sensors with long range reach

They have watched underwater volcanoes, inspected icebergs from below and kept tabs on whales. More often, oceanographers use them for the long, tedious job of collecting data on water temperature, opacity and salinity, and the speed of ocean currents. They provide a continuous picture rather than just snapshots at long intervals, sending back data via satellite when they surface.

There are three commercial varieties, all from the US and all with the same winged-torpedo body shape – iRobot's Sea Glider, Teledyne Webb's Slocum Glider, and Bluefin's Spray Glider. Endurance is currently a matter of months, though Teledyne Webb have also designed a version with a thermal engine which can extract energy from the temperature difference at different depths and continue indefinitely.[26]

An array of Teledyne Gliders

With no propeller noise, gliders are extremely quiet (and stealthy), and can carry acoustic sensors so sensitive they can, as one researcher put it, "hear a fish fart". This is not an exaggeration: a project on the West Florida Shelf had a glider tracking shoals of grouper and toadfish by the sounds they made.[27]

Military Gliders

Gliders have obvious military applications in ASW. As a thesis on gliders by William Parker for the Naval Postgraduate School simply puts it:

> *"A fleet of gliders could also provide a low cost network for determining the patrol patterns of threat submarine fleets."*[28]

The US Navy has undertaken a number of glider projects.

The Persistent Littoral Undersea Surveillance[29] (PLUS) system currently consists of five iRobot Sea Gliders and six conventional REMUS 600 UUVs networked together. Its aim is to "to detect and localize targets in support of anti-submarine warfare operations." PLUS is intended to give persistent surveillance of multiple quiet targets using passive sensors, with later developments adding active sensors.

An X-ray drone, predecessor to the Z-Ray

Littoral Battlespace Sensing-Glider (LBS-G) program will involve up to a hundred and fifty Teledyne Webb gliders.[30] This is concerned with measuring water conditions as they affect sound and light. Layers of water of different temperatures affect the sonar reflection and transmission, and the cloudiness of the water determines how great a depth can be seen through (and at what distance laser sensors and communications will work). LBS-G provides a means to measure these and other factors remotely.

A previous project was the Liberdade Z-Ray, a more sophisticated glider, designed by the US Navy.[31] It is larger than the others and resembles a stealth bomber with a six-metre wingspan. The aerodynamic design gives it low drag and good lift; the Z-Ray cruises several times faster than other gliders at three knots. The prototype has towed broadband acoustic sensors, designed to locate quiet diesel-electric submarines (generally more stealthy than nuclear-powered varieties), taking advantage of the Z-Rays own near-silent operation. Z-Ray's first mission was tracking whales off California by following their calls. Development was apparently discontinued in 2012.

The Wave Glider developed by Liquid Robotics Inc is the system described in the scenario above, a hybrid USV/UUV with a small surface unit tethered to an underwater glider, propelled by wave power.[32] The Wave Glider proved its endurance by completing a one-year, 9,000-mile Pacific crossing in 2012.

A specially-designed acoustic sensing system known as Sensor Hosting Autonomous Research Craft (SHARC) Towed Array Integrated "L" (TAIL), which would be towed by the Wave Glider's lower unit, was developed under a Navy contract in 2012.[33] The Wave Glider's solar array gives it additional power for sensors which would not be possible for underwater gliders which work on a much more limited energy budget.

Part 3: Future Gliders

Scenario 3: Swarms of underwater drones

An intricate dance is taking place in the South China Sea. The dancers are two shoals of fishlike swimming robots; they circle around each other, or drop to the sea bed. Some are trying to follow the robots on the other side; some are trying to slip past and remain unobserved. They bunch together, dart in all directions, or attempt to conceal themselves in floating patches of weed.

The sea here has a faint noise not heard elsewhere; it closely resembles the usual hum of underwater activity, but it is actually the sound of chaotic acoustic communications.

These are underwater modem signals carefully blended to match the background noise, the chatter of the two shoals as they locate, identify, classify, and try to keep tracking the other side.

Shipping passes by above, but there are no vessels underwater bigger than a shark. This underwater world of gliding robots, some carrying sensors and some carrying warheads, is not safe for manned submarines. Anything so big and noisy would be instantly spotted and targeted, and as well as their own weaponry both shoals can call on formidable air support. Underwater warfare is now exclusively the domain of robots.

Current gliders are comparatively expensive, $50,000 or more. This makes them affordable for oceanic research; with survey vessels costing thousands of dollars a day, gliders are a low-cost option. There has been little incentive for manufacturers to bring costs down, but gliders can be produced far more cheaply.

Just as consumer drones have made what used to be an exclusive military capability affordable, there are also cheap gliders. Professor Masakazu Arima of Osaka University has created a low-cost glider called ALEX which is about a metre long and a tenth the weight of other gliders.[34] Its wings can be moved independently, giving ALEX good manoeuvrability. Arima is interested in robotic swarms and has proposed deploying "about a thousand" underwater gliders, to form a vast co-operative network to measure and survey the oceans. (Arima has also designed a glider called SORA which incorporates solar recharging).[35]

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The Mini Underwater Glider (MUG) also designed at Osaka University takes the idea even further.[36] MUG is a low-cost educational platform for students which can be made with basic tools from easily-available components. The developers estimate that the two-kilo glider can be assembled for around $35. All it then needs are electronics to provide sensors, navigation and communications – exactly the sort of capabilities provided by cheap mobile phones.

Perhaps the most important country to look to in underwater gliders is China. A US counter-intelligence report in 2010 noted that the Chinese were targeting this technology specifically.[37] The first indigenous glider, the Sea Wing, was developed at Shenyang Institute of Automation in 2011.[38] It was designed for deep-water research and reportedly carried out several successful missions in the Western Pacific.

Projects at Tianjin University have aimed to extend the endurance of underwater gliders. The Dragon is fitted with a fuel cell rather than lithium batteries, offering perhaps ten times the energy density and a mission duration measured in years.[39] Another glider will have a 'temperature difference engine,' a copy of the thermal glider pioneered by Teledyne Webb.[40] Another project, this time at North-western Polytechnic University at Xi'an, is building a wave-powered generator for gliders.[41]

Chinese researchers have also been seeking ways to get around the glider's limited tactical speed by creating hybrids with additional means of propulsion. The Petrel (in Chinese, Haiyan) is one such a hybrid craft from Tianjin University, with a propeller as well as buoyancy engine.[42] It can glide for the long-range, long-endurance part of its mission, or switch to the propeller for rapid short-range manoeuvring. Petrel carried out field trials at Fuxian Lake, and there is now an improved design, Petrel II.

The developers note that Petrel II "has the ability to dock with an underwater station for battery recharging and data communication, which will further expand the range and endurance of the vehicle."[43] This suggests an approach in which several gliders cover an area, returning to the recharging station at intervals.

Further research at Tianjin University has looked at path planning and software for the co-ordination of swarms of underwater gliders working together.[44]

Meanwhile Xi'an researchers are making gliders more agile. MWUG is the Moveable Wing Underwater Glider; most gliders have fixed wings but MWUG can move its wings independently, making it faster and more efficient.[45] A second project takes this even further, with wings which act like a turtle's fins to provide additional stealthy propulsion without the noise of a propeller.[46]

In fact, China is a world leader in the area of 'robotic fish' which silently propel themselves with fins.[47] Gliders incorporating this technology could put on a burst of speed without compromising stealth, and retain the gliders long endurance for extended missions.

Putting this together, the Chinese are developing the technology to field large numbers of long-endurance gliders, working in co-operative groups, and which will be capable of greater speeds than their Western counterparts. While we have no direct access to Chinese military efforts in this area, the academic base clearly exists for military glider development.

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The dual-powered Petrel, or Haiyan, from Tianjin University

The Petrel or Haiyan, is currently used for scientific research, but Chinese State media have stated that "the UUV can also be upgraded by the Chinese Navy to serve as a[n] underwater combat and patrol robot, taking on lengthy and dangerous missions like minesweeping and submarine detection, and offer[ing] protection for Chinese ships and oil platforms." [48]

Elsewhere it has been suggested that the new Shaanxi Y-8Q ASW aircraft will act as a flying control centre for multiple Haiyan gliders, using them to gather targeting data.[49]

In the past, submarines have enjoyed the luxury of hiding in empty seas. In the future, those seas are likely to be increasingly crowded with networked drones, a net of eyes and ears which no submarine can escape.

Appendix

Technical note on sensors and communication underwater

Paul Ingram

Anti-submarine Warfare (ASW) technologies, particularly sensors, are rapidly developing, assisted by extraordinary leaps in the scale and capabilities of computing power. These leaps in computational capabilities enable very subtle changes in the environment arising from the presence or activity of submarines to be detected. Typically less accurate sensors may be used to establish the presence of a contact, and then more accurate sensors pin-point exact position and identity, enabling a coordinated attack. Evolutionary gains in sensors include reduced size and cost, and their greater capabilities to detect at greater range.

Sonar and acoustic

The traditional approach to detecting submarines using sound waves has led to high-tech competition between passive and active sonar sensors, and evasion by submarines. Static hydrophones and sonobuoys have been detecting submarines for decades (the US Navy established an extensive Cold War ocean sound surveillance system - SOSUS). Sonobuoys are dropped from ASW aircraft when they suspect a submarine is in the vicinity. In future they are likely to use arial or underwater drones. Beamforming techniques have been developed recently that combine the signals from all sensors in a network to form accurate acoustic imaging of a wide area.

Mobile active and passive sensors on towed arrays on ships, submarines and drones have become highly efficient in detecting acoustic signatures and pin-pointing the source. Active systems involve a source emitting an acoustic signature which can then be detected by sensors many miles away to form acoustic imaging.

In response submarine manufacturers have developed technologies to evade detection and attempt to cloak submarines, such as acoustic tiles and highly efficient, quiet reactors and propulsion technologies, and means to minimise other noises produced within submarines. Nevertheless, these evasive technologies are not perfect, and modern sensors, when they are close enough, can detect the stealthiest of modern submarines.

The CTBTO operates a network of hydroacoustic monitoring stations for the purpose of detecting nuclear tests, but these stations pick up a large frequency spectrum of noise in the oceans, and would undoubtedly have a limited capability to pick up the sound from submarines.

Sound can travel very long distances in water with little loss of signal, particularly in deep sound channels across extremely large distances. It can therefore be useful in communication - submarines use it to receive signals. Whilst sonar using longer wavelengths travel long distances they have a lower bandwidth. Yet with far greater computational capacity, this bandwidth can contain sufficient information to be useful in transmitting data. One problem with using acoustic methods of communication is that it reveals the location of the object transmitting.

NATO's CMRE research centre in Italy has been working with European partners to create a system of AUVs that communicate through acoustic modems in an underwater wireless network so that they can be controlled remotely or controlled autonomously as a whole system.

The NATO Undersea Research Centre (NURC) is also investigating an alternative approach whereby individual sensors and underwater assets are autonomous and follow a behaviour or algorithm to position themselves in relation to each other and other factors (using sensing and mapping technologies) to optimise the chance of detecting targets and their own survival. The concept of use of underwater multiple vehicles interacting only by means of underwater communications is receiving a great deal of interest and prompting many areas of research including robotics, communication theory and multi-static tracking.

Magnetic Anomaly Detectors (MAD)

Large ferromagnetic objects (like submarines) can create a local disturbance in the Earth's magnetic field that can then be picked up by a MAD. Versions of MAD were used in WW2, and they form a mainstay of ASW on planes and helicopters, using towed arrays. As with all other detection technologies, it suffers from the inverse square law, so detectors need to be within a couple of km of the target.

MAD detectors are becoming far smaller and their accuracy is improving, particularly with the development of SQUID (Superconducting Quantum Interference Device) and the ability to deliver micro supercooling units. SQUID is so sensitive to magnetic variation it can detect small seabed mines.

Stealth options involve constructing the hull of the submarine out of non-ferrous material (such as titanium), but this can have only limited effect as so many components are unavoidably made of ferrous material. There is no hint that new submarines will be made of non-ferrous materials.

MAD may become the critical component of the detector technology used on drones described in the previous sections (particularly UAVs). It will be used on many more and smaller networked sensors widely distributed in the air and in the sea, combined with a massive increase in computational capabilities allowing for greater sensitivity in interpreting the data and thereby increasing the range significantly.

Hydrodynamic pressure wave detection using optical and radar techniques

Submerged submarines leave a wake within the water which can be detected undersea or at the surface. Obviously this is more pronounced when the sea is calm, but with powerful enough radar and computing capacity it is possible to detect wake even when the sea is rough or there are strong currents. Optical and radar sensors achieve this by mapping the surface and detecting the anomalies created by the wake. Such techniques using Synthetic Aperture Radar (SAR) is likely in future to be particularly useful on larger UAVs dedicated to ASW.

Electro-optical / infra-red / thermal imaging technologies

These may pick up traces of electro-magnetic radiation directly or more likely indirectly in a similar fashion to the wake detection, arising from plumes of heat radiating from the submarine and rising to the surface. In future there may be possible hyper-spectral imaging sensors able to pick up differences in heat in the water.

Radiation detection arising from reactors

There have been developments in anti-neutrino detection techniques, though it remains unclear how far advanced these are and whether they will ever be effective and small enough to include on smaller platforms.

Laser and LED detection

Water is generally opaque to electromagnetic radiation over long distances, but visible light (using asers and LED at specific wavelengths) can travel over some hundreds of metres without significant degradation. Particular types, including LIDAR (laser radar) sensors, have been used to map the sea bed or to detect objects in between.

Selected further reading

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About BASIC

BASIC seeks progress on the vision of a secure world free from the threat of nuclear weapons, involving a global move away from reliance on nuclear weapons within national security doctrines, leading to worldwide nuclear weapons disarmament, strong international measures to assure non-proliferation, and stronger international conditions and public opinion that underpin this.

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BASIC set up a three year review of Britain's current nuclear weapons policy in 2011 led by Sir Malcolm Rifkind MP, Lord Browne and Sir Menzies Campbell MP. The Commission comprised eminent members of the British political, security, diplomatic and scientific community, which completed a final report agreed by consensus, published in July 2014. The report was intended to inform the debate, not close it down. Commission members unanimously expressed their belief that this is a critical issue in its own right, and that the issues needed further consideration.

This series of briefings is intended to update Parliamentarians of critical, relevant issues in a year when the government intends to bring the issue of Trident's posture and the project to renew the system to a vote in the House of Commons. The briefings adopt the spirit of the Trident Commission, highlighting the need for Britain and other nuclear weapon states to consider more seriously the 'glide path' down the nuclear ladder.

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26 February 2016