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British Pugwash workshop:

Emerging Undersea Technologies

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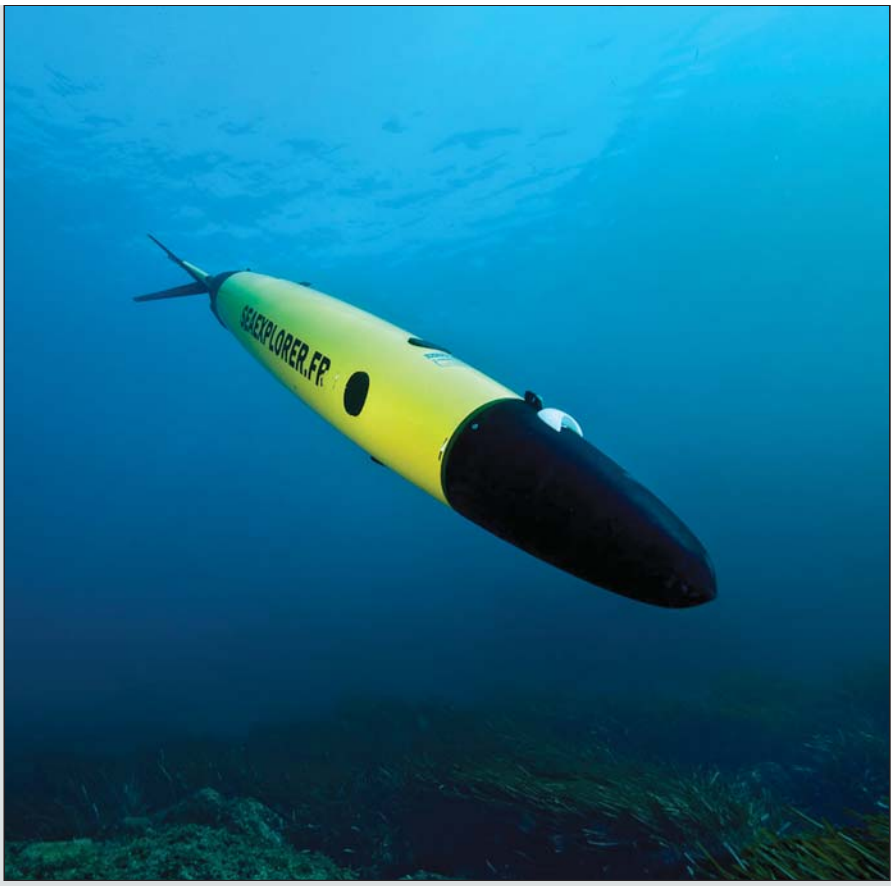
Introduction

The workshop brought together seventeen scientists, technical experts and academics from the US and UK to assess current and emerging undersea technologies, their likely future direction of travel, and the implications of developments in sensing, computing and communications for the undersea battle space.

The morning sessions concentrated on developments in underwater sensing and communications technologies and advances in marine robotic vehicles. The afternoon session focussed on the implications of these for the deployment, strategy and modalities of SSBNs.

The day began with a short video overview of this subject taken, with his permission, from Bryan Clark's presentation of his report, "The Emerging Era in Undersea Warfare".[1] to the Centre for Strategic and Budgetary Assessments (CSBA) in January 2015

A former US submariner, Bryan Clark was, until 2013, Special Assistant to the US Chief of Naval Operations and Director of his Commander's Action Group, where he led development of the US Navy strategy and implemented new initiatives in electromagnetic spectrum operations, undersea warfare and expeditionary operations.



Seaexplorer underwater glider diving   Photo (cc) by Yann le Page

The conclusion of the above report states:

"The emerging era in undersea competition will require a significant rethinking of how military forces conduct undersea warfare. Dramatic changes are occurring in the technological realm that should inform new operational concepts, which will have significant implications for kinds of undersea capabilities that should be developed and the ways in which larger naval and joint forces should evolve to complement them."

1 Bryan Clark's presentation to the Centre for Strategic and Budgetary Assessments (CSBA) in January 2015 of his report, "The Emerging Era in Undersea Warfare" www.youtube.com/watch?v=TLmM8PK2bos

Session I:

Developments in Sensing and Communications Technologies

Professor Nicholas Makris, of Massachusetts Institute of Technology and Director of the Laboratory for Undersea Remote Sensing, gave a presentation on developments in instantaneous acoustic sensing of the undersea environment over areas spanning tens of thousands of square kilometres.

He discussed the use of active and passive Ocean Acoustic Waveguide Remote Sensing (OAWRS) to instantaneously sense over very large areas. OAWRS relies on the capacity of the ocean environment to behave as an acoustic waveguide, in which sound propagates over long ranges via trapped modes. Therefore, generated sound waves suffer only cylindrical spreading loss rather than the much greater spherical loss suffered in conventional fish finding technologies.

Professor Makris stated that his goal as a scientist is to make the oceans as transparent as possible, in order to understand it better, focussing on acoustic techniques. As sound travels at 1.5km/s in water, Professor Makris noted that using OAWRS techniques, his team is able to view a 100km diameter area in about 90 seconds and update the image every 90 seconds to make a 'movie'.

They are able to detect different objects in the water, from herring shoals containing many hundreds of thousands of fish, to a small man made object (a long cylindrical inflated fire hose around 10m long), using different acoustic frequencies that excite different resonances.

While lower frequencies of around 200Hz are typically dominated by shipping noise, using a passive acoustic array his team can detect and localize many species of whales over areas spanning 400km in diameter, from hundreds of thousands of whale calls each day. His findings have been published in journals including *Nature*[2] (passive sensing/whales) and *Science*[3] (active sensing). Sensors can be either bistatic (sender and receiver separate) or monostatic (sender and receiver at roughly the same location).

In later discussions between participants it was made clear that it is the ability to find the frequency that gives the best returns from an object, and therefore gives the best strength of image against the background scatter, that is the key to detecting anything from a single fish to a submarine. An example was given where it is possible to "sense a single salmon out to about 3km, and resolve it over a background scatter with relatively simple standard systems. If you pick the resonance frequency of the salmon."

It also became clear in discussion that the same techniques that can separate the individual calls, acoustic signatures, of different whale species over vast areas, as described above, are applicable to detecting and identifying the different acoustic signatures of submarines.

2 "Here we use passive ocean acoustic waveguide remote sensing (POAWRS) in an important North Atlantic feeding ground to instantaneously detect, localize and classify MM vocalizations from diverse species over an approximately 100,000km square region." *Nature*, Volume 531, 366–370 (March 17, 2006) www.nature.com/nature/journal/v531/n7594/abs/nature16960.html

3 N.C. Makris, P. Ratilal, D. Symonds, S. Jagannathan, S. Lee, R. Nero, "Fish population and behavior revealed by instantaneous continental-shelf-scale imaging," *Science*, Volume 311, 660-663 (February 3, 2006)

Professor Yvan Petillot, Head of Research Institute, School of Engineering & Physical Sciences; Sensors, Signals & Systems, Heriot-Watt University presented on:

- Underwater multispectral LIDAR.
- Underwater acoustic imaging (how to create high-resolution maps from high frequency sonar).
- New Multiple Input/Multiple Output (MIMO) systems for improved acoustic imaging.

Professor Petillot described the difficulties in using optics for sensing in the ocean because of the limited range of transmission. However, he told us of recent advances using Multiple Input Multiple Output (MIMO), an acoustic system that uses simultaneous transmission and reception from multiple transmitters and receivers. He outlined the difference the configurations of these components can make, with the best configuration being an octagon and the worst the classic straight line. As MIMO provides multiple views of the same object from different directions, it therefore results in greater resolution of the object.

This system would be useful, for example, for tracking a target entering a harbour, after which an underwater vehicle might be dropped to investigate further. It is also useful for tracking depths of objects with a precision of 50 metres and, with for example a standard 10 calibrated array (10 transmitters and 10 receivers), for identifying the speed and direction of the vehicle.

In parallel, work has been done on photonics and Light Detection And Ranging (LIDAR) technology that uses light sensors to measure the distance between the sensor and the target object. Although light does not propagate well underwater generally, the blue / green region of the spectrum suffers significantly lower losses and so is potentially exploitable underwater. Hence, much LIDAR work has been undertaken using blue / green lasers developed for underwater use. It was found that by sending out a million laser pulses, a return of around 20 is sufficient to create a usable image at longer underwater ranges than can usually be done with optical techniques.

Using a continuous laser with multiple networks it is possible to detect the different colours and shapes of objects, which is useful for example for detecting a man-made object from surrounding foliage.

Underwater communication using the blue / green spectral region is also being investigated, for example by BAE Systems and by the Chinese. It is thought that they are finding that for communications using optics the useful range is about 100 metres - any further and the photon return is too small. This range might possibly be increased to 200 – 300 metres, though that would require much greater power.

Optimal ranges of sensors

In a further effort to clarify this after the workshop we learnt that good 'rules of thumb' would be the following:

0-100m (in ideal conditions): Lasers can be used effectively. Relatively high data rates of 10-100Mb are achievable.

100-500m: acoustic MIMO can be used effectively, with 'reasonable' data rates of 20-100kb/s

500-2km: acoustic MIMO but with lower data rates of 2kb/s-20kb/s

Further than 2km: acoustic MIMO but with very low data rates of 50bp/s

The best performances are obtained on a vertical channel with little multi-path and seabed reverberation effects. This would be for an Unmanned Surface Vehicle (USV) communicating with an Unmanned Underwater Vehicle (UUV).

For UUVs communicating with UUVs, you would typically be restricted to 2kb/s over a 2km range. For longer ranges, it would go down significantly.

In summary, it was thought that the significantly higher bandwidth of optical systems is much better suited than acoustic systems for short range communication and identification of targets where a large amount of data is to be transferred. However, the transmission losses limit the distance over which they can be effectively used, though with increasing power the range can be increased to some extent. LIDAR is cost-effective, can be small enough to fit on a Unmanned Underwater Vehicle (UUV) and operate within a range of a few hundred metres.

Professor David Caplin, Emeritus Professor of Physics, Blackett Laboratory, Imperial College London, gave a presentation on the developments in magnetic sensing.

Professor Caplin began by stating that any iron or steel object gradually becomes magnetised by the Earth's magnetic field. This has been known for a long time and hence submarines are regularly demagnetised ('degaussed'). The magnitude of the residual magnetism is highly-classified, but a rough estimate might take it to be 0.1% of full magnetisation.

He went on to speak in more detail about one type of magnetometer, the Superconducting Quantum Interference Device (SQUID), that typically can detect a small bar magnet at hundreds of metres. As it detects magnetic fields by measuring the magnetic flux passing through a 'loop', the larger the loop the more sensitive the device.

The magnetic signal from a submarine drops away as an inverse cube law, becoming smaller than the Earth's field within hundreds of metres. In principle, the signal would still be detectable at tens of kilometers, but difficult to discriminate against the Earth's field. The standard geophysical approach is to connect two anti-parallel loops to one SQUID that cancel the Earth's uniform background field, but pick up the magnetic field gradient of the submarine; the effective range of this gradiometer configuration might be several kilometres.

SQUIDS can be flown on aircraft that would then need to fly low to be effective.

One significant change in SQUID detection in recent years is that where previously superconductors had to be cooled to near absolute zero temperatures with liquid helium, there are now high-temperature superconductors which superconduct at temperatures up to 150K. This still requires liquid nitrogen cooling, which complicates their deployment in anti-submarine warfare (ASW). However it is not out of the question – given the many surprises in the history of superconductivity – that materials may eventually be found that superconduct at room or ocean temperatures, which might allow the deployment of very much larger flux loops, and so increase sensitivity by orders of magnitude.

Another type of magnetic field detector is the fluxgate magnetometer. This may be of more use in ASW in the near term, as it can be put into a gradiometer configuration (as with the SQUID), is very cheap and easy to deploy, and functions at ocean temperatures. Another participant added that the US Navy (which has a large ASW programme) is currently working on fluxgate arrays.

Open discussion session

In discussion, various other types of system for detecting submarines were felt to be worth investigating, including wake detection; thermal anomaly detection; bioluminescence; and perturbation of the gravitational field.

Wake detection was discussed a little further. It was argued that a lot can be seen from satellite and aircraft imagery of wakes / straight lines on the surface of the water. Although these surface lines can be associated with various underwater phenomena, suspected images of wakes from submarines could be compared against baseline images of the ocean to detect changes from normal. It was stated that the Russians have a theory of 'fossil turbulence' that remains from hours to a day after a submarine has passed, an idea that has been laregely dismissed in the West to date. However, there may be something in it – for instance, harbour seals can use their whiskers alone to follow fish at 200 fish lengths, and submarines leave much larger wakes than fish and they persist much longer.

Sensor Fusion and Networked Systems

There was general consensus that the most effective way to find submarines would ultimately be through 'sensor fusion', in which several of the above techniques are combined. As one technique may yield false positives, candidate signals could be verified using different techniques that use different modalities. It was noted that different personnel and commands within the current organisational regime tend to focus on individual detection techniques, rather than combining their data. However the continuing development of 'big data' makes this kind of sensor fusion likely. An ability to network sensing from satellite, surface vehicles and underwater unmanned vehicles was seen to be a key major development for future detection.

Skill levels

Another issue raised was a loss of skills and experience. The crews of submarines are highly skilled in both hunting submarines and avoiding detection, and these experienced staff are not being replaced with young blood.

Countermeasures and Camouflage

The ability to reduce the overall acoustic signature of submarines was discussed – and whether this would be sufficient to maintain stealth. This reduction would offer no protection from detection systems that do not rely on acoustics, such as LIDAR, although attempts to provide camouflage from other systems might end up compromising acoustic camouflage.

Session II:

Developments in Marine Robotic Vehicles

David Hambling, Freelance Journalist who writes for New Scientist, WIRED, Economist, Guardian and other publications and author of Swarm Troopers (2015), presented on:

- The emergence of small, low-cost drones as viable platforms for tasks including ASW
- Air-launched drone swarms, specifically the Coyote and how this might be used for ASW
- Underwater gliders, specifically the Chinese Haiyan/Petrel and US Amphibious air/surface drones and in particular the Quad Aqua, a pack-hunting, solar-powered flying sonobuoy.

Mr Hambling argued that advances in mobile phone technology have enabled drones to become much smaller, more capable, relatively cheap and potentially available in very large numbers. The size of the drone is now determined by the size of the payload, and as sensors are becoming increasingly miniaturized, they can be deployed on smaller drones.

These drones, he said, will be able to function semi-autonomously or autonomously in swarms, an operational mode that has already begun to be used. The US has about 10,000 drones, of which 9,000 are small and hand-launched, while, in the civilian world, the Chinese company DJI is selling 1 million highly capable drones a year, each equipped with movie-quality cameras. Mr Hambling noted that for the cost of a few bigger drones (such as the US's MP4 Triton, which each cost $100m), a military could build a million smaller drones

Mr Hambling gave examples of three types of drone, each with the potential to revolutionise submarine warfare:

The Coyote, an air-launched drone, is usually used for hurricane research and can be dropped into areas manned aircraft cannot reach. It has a flight time of 90 minutes and beams back data from 50 miles. In one scheme twenty or twenty five of these could be dropped together equipped with magnetic anomaly detectors and cover several thousand kilometres in one hour. This is a much greater search area than any single manned aircraft can achieve.

The Aqua Quad can be seen both as a quadcopter with solar-powered cells, and as a reinvention of the sonar buoy. Unlike present sonar buoys, it can launch off the water and fly to new locations, enabling it to remain near its intended target. It can have a life of several weeks to several months and has been designed from the start to work 'as a swarm' with large numbers working together to form a sonar array over a wide area that is able to relocate as needed. According to a US Navy representative, the Aqua Quad is "better than what we have now".

The Haiyan/Petrel, developed by the Chinese, is an underwater glider launched in 2011 and being developed for anti-mine and anti-submarine purposes. The Chinese have also been looking at swarming software to enable large numbers of unmanned vehicles to operate cooperatively.

The underwater glider, originally invented in the US in the 1990s, uses a buoyancy engine. It is almost noiseless, making it good as a sonar platform. These underwater gliders move very slowly, at one knot maximum, but use very little power.

They surface every few hours to communicate back to a satellite but are capable of carrying on autonomously for very long distances. One of these crossed the Atlantic in 2009 taking seven months.

Mr Hambling felt that we were only at the start of discovering what drone swarms can do, but that there is every chance that they will have a revolutionary effect on submarine warfare.

Professor Russell Wynn, Chief Scientist, Marine Autonomous and Robotic Systems (MARS), National Oceanography Centre (NOC), Southampton, presented on: The revolution in marine data gathering using robotic vehicles, including the transition from vessel-based, high-power, low-endurance remotely operated underwater vehicle (ROV) and AUVs, to more dispersed fleets of low-power, high-endurance vehicles such as submarine gliders, unmanned surface vehicles (USVs) and long-range autonomous underwater vehicle (AUV)s.

Professor Wynn outlined the significant government investment in research at the NOC on new autonomous platforms for science. He showed illustrations of their fleet of autonomous vehicles, which he described as one of the most capable in the world, and compared the cost of this fleet as a fraction of the cost of a new ocean-going research ship. Professor Wynn described his work as innovative science, getting into parts of the ocean that are difficult to reach using conventional means. A lot of work has been done under the Antarctic ice using autonomous vehicles to map the sea bed, and quantify biomass.

Other science applications for AUVs have included sniffing for the chemical signature of active hydrothermal vents, and then, using an ROV, collecting impressive underwater images.

He told the workshop of NOC's work to develop a long range AUV that will have an endurance of several months, be able to go down to 6000m, and travel for hundreds if not thousands of kilometres. In five years, NOC aims to have a AUV able to cross the North Pole under the ice.

A key future development is the exploitation of 'artificial intelligence', where instead of routinely collecting and transmitting large amounts of data the software will identify key data to prioritise. This will allow the vehicle to choose which data to send back, thereby lowering bandwidth requirements, and to detect anomalies and switch on sensors and cameras to perform high-level resolution data collection on the object.

Another key to maximising the capability to collect data is to use combinations of vehicles. One vehicle could map the seabed while another is collecting close-range seabed image data and yet another, a submarine glider for example, is collecting data from the water column so that you can "do the geology, biology, the oceanography, all in a tightly defined period," bringing costs down and maximising data collection.

NOC is also looking at more automated and intelligent command and control of all the different systems. For example, Rolls-Royce has a concept whereby future fleets of freighters might operate unmanned, with one controller on land commanding the fleet. In five years time NOC aims to be able to have one person safely control a fleet of unmanned vehicles from a laptop at any location.

Open discussion session

Collective noun

We considered whether it is better to imagine these drones as 'swarms', 'flocks' or 'packs', which tend to operate in slightly different ways. While some roboticists use the term 'swarm', and there may likely be military purposes for 'swarms', others saw no scientific interest in programming these robots as 'swarms' and saw them acting collectively as a 'pack'. It was felt that this will probably depend on who is programming the robots and for what purpose.

Communications between drones

It was stated that UUVs could communicate with each other and USVs acoustically over a few kilometres, although there are limits on bandwidth. They could also use LIDAR over smaller ranges, which have higher bandwidth, and magnetic communications, which might be slightly longer range than LIDAR. It would be possible to have a 'mother' craft, such as the US' Large Displacement Unmanned Underwater Vehicle (LDUUV), which could launch and recover smaller craft.

One participant suggested that it would be preferable for a UUV to collect as much information as possible on a single mission, and then transmit it when higher bandwidth becomes available, for example on surfacing. However, this might not always be mission appropriate.

Speed

Most UUVs move at 2-4 knots, or about walking pace. SSBNs also move at walking pace routinely, making them harder to detect. However, they can probably outrun most surface vehicles if necessary, although new surface vehicles – such as DARPA's new automatic trimaran, Sea Hunter – are designed to keep pace or overtake them.

Payload

A UUV's payload is a trade-off between the size of the payload (such as more sensors) and the UUV's endurance/power requirement. There doesn't seem to be a natural limit on size.

Safest place for nuclear weapons

Although there was general agreement that the oceans remain the safest place to hide nuclear weapons at present, we were encouraged to take a critical attitude towards this in the light of scientific and technical developments such as those discussed in this workshop.

We were reminded that the team considering the Trident Alternatives Review had looked at over 300 different options, including a barge on the Grand Union Canal! Although it is recognised that we may be faced with increasingly transparent oceans, a decision had to be taken at some point on replacement and this was perceived by that team as the best option.

It was noted that ocean transparency would only be available to a few states, the number of countries that can send vehicles to depths of 6,000m or travel under deep ice sheet are perhaps the same number as may perhaps get to Mars.

Session III:

Implications for Undersea Deployment, Strategy and Modalities

Paul Ingram, Executive Director of the British American Security Information Council (BASIC) spoke on: Drawing together the assessments of the state of relevant ASW technologies, to assess what future risks they pose to the specific SSBN mission and how these could impact upon strategic stability and the credibility of nuclear deterrence based upon the SSBN.

Mr Ingram felt that the recent media interest in the issue of the vulnerability of Trident had prompted a response from the MoD in a ministerial statement, which makes two claims:

- That it will be "unlikely" that the oceans will be sufficiently transparent to pose a threat to the Trident system.
- That "in any event," a submarine will be the least vulnerable system.

Mr Ingram agreed with the minister that we do not yet know the future impact of the emerging technologies, but as there is strategic uncertainty, we need to understand this technology.

However he took serious issue with the claim that submarines are the least vulnerable platform even if detectable. He argued that if the advantage of stealth is removed from an SSBN then it is even more disadvantaged than others systems. They are slow, with low situational awareness and have relatively few in-built countermeasures. Moreover, they are vulnerable as targets as they sit in international waters and are known to operate in 'boxes', defined areas of ocean. While SSBNs are not constrained to these boxes, their known existence helps states narrow down their search areas. Further, any attempt to attack UUVs or other ASW systems by the SSBN would harm its stealth and so be counterproductive. It may also be considered an act of war, although it might be argued that this norm will change over time.

Mr Ingram noted that submarines already go through 'de-lousing' when they come in and go out of port, though what this entails in detail is classified.

Another problem is that SSBNs are part of a system of systems that are procured with a long lead-time, around 17 years in the UK, entailing an inherent degree of inflexibility to subsequent modification.

This can be contrasted with the number of generations of UUV that can be developed in that time: UUVs are fast to produce and can hence keep up with developments in technology, cheaper and more expendable, and can host a range of up-to-date sensors.

The direction of travel in ASW is clearly toward greater transparency. This is considerably enhanced by the continuing extraordinary development of computing capability, which itself is a key factor in the increasing effectiveness of sensing.

He felt that although the technology needs to mature, and these developments do not completely shift the decision on Successor, we have a responsibility to take these issues into account in planning future expensive systems.

Following Mr Ingram another participant agreed that, as this technology advances, it will become easier to "detect, locate and prosecute" submarines, but that the UK is likely to find appropriate countermeasures. The question is whether the cost and effectiveness of these countermeasures will begin to outweigh the risk to a point that the UK cannot justify continuing with SSBNs. It should be questioned however, whether the UK's previous successes in developing countermeasures assure success in doing so in the future.

It was noted that when many alternative platforms for the UK's nuclear arsenal were investigated, submarines were chosen because they were seen as the most viable. The alternatives would have included a silo field the size of Wales or multiple airfields, which are both unviable and vulnerable to first strike.

Open discussion session

It was pointed that the sea is a vast area to search, the Atlantic alone being 15million square kilometres. Moreover it was pointed out that the ability to detect a submarine is not the same as being able to track and destroy one.

Even if a submarine were to be detected, there would still be an extended response time from 'find/track/destroy' to enable the submarine to evade the detector. However, it was noted, it is not always necessary to destroy a submarine but only to prevent it carrying out its role.

In later discussion it was noted however that usual practice in oceanography is to make use of 'gateways', or 'choke points,' as they are more commonly called in military terms, through which an SSBN must at some time pass, and that there are a relatively few number of these.

The workshop looked at a brief history of submarine hunting. The UK and US "sonar advantage" allowed them to track Soviet submarines until the Walker Spy Ring informed the Soviets of their vulnerabilities. However it was felt to be worth looking at the significant impact of the use of sound surveillance system (SOSUS) during the Cold War. This was particularly effective in the 'GIUK Gap' choke point, the area between Greenland, Iceland and the UK.

Recommended follow up resources included a book, *Blind Man's Bluff* (1998), and TV specials associated with the book, possibly on NOVA or a similar scientific documentary programme within the last couple of decades.

One of the biggest changes was stated to have been the introduction of passive towed array sonar behind the submarine. This had much better processing power than predecessor systems and could detect other submarines "many, many miles away." Acoustic detection became so good that individual submarines' signatures could be detected, though these signatures are highly classified. It was noted that, through using static inverters and rotating machinery, the UK Vanguard class are even quieter than the Resolution class were.

The next big change, one participant noted, would be SSBNs going "on the offensive" to prevent detection.

Summary and further research

Professor John Finney, Emeritus Professor of Physics, University College London, London Centre for Nanotechnology summarised the key findings of the day.

He reviewed the technologies that had been covered, and the questions raised for the future on how far this technology will continue to progress in terms of increasing range, image resolution, bandwidth and speed of communication.

OAWRS

At present low frequency active and passive sonar is the most advanced sensing technique for long-range detection of very quiet or even silent submarines and for long-range communications, albeit limited by bandwidth to low data rates. As noted in the article in Nature,[2] passive ocean acoustic waveguide remote sensing (POAWRS) can instantaneously detect, localize and classify whale vocalizations from diverse species over an approximately 100,000km square region. This gives a good indication of what can be achieved in detecting, localizing and classifying the acoustic signature of an individual submarine at a considerable distance.

Blue / green lasers

Optical detection and communication using blue/green lasers have a relatively short range at present of around 100m, rising to perhaps 300m with decreased quality of returns. But the high bandwidth is potentially very useful for data exchange, for example between underwater robotic vehicles or between a UUV and an underwater charging station and communications relay such as one similar to the Forward Deployed Energy and Communication Outpost (FDECO). These, and others used by the oil and gas industry, could act as rest stops for UUVs where they can download data and upload orders while recharging their batteries.

How far could the range over which blue / green lasers are effective be increased by increasing the power of the emitting laser and/or the sensitivity of the detector of the returning photons?

Wake detection technology was not discussed in detail but this is an area felt to be well worth looking at more closely.

Anti-neutrino technology is not perceived to be deployable for submarine reactor detection in real time at present or in the next few years.

However, as work is known to be under way on this technology, it is possible this assessment may change in 20 years time and so a watching brief on its development should be maintained.

‘Big Data’ processing

Key changes that continue to enhance the effectiveness of the different sensing and communication technologies have been the advances in computing processing power and the increased range of platforms on which these technologies can be deployed and networked. Big data is currently a booming industry and can be expected to advance significantly in the next decade or two, such that many of the challenges that sensor and drone technologies face today, with respect to detecting small changes or complex decision making, may be solved by the time the Successor Programme is operational.

As this and miniaturisation of technologies develop further, what is the potential to further enhance the effectiveness of underwater sensing technologies?

How might this, for example, influence the current trade-off between endurance and payload?

Sensor fusion

Another potential ‘game changer’ would be to network a range of sensing techniques and host platforms to create sensor fusion. However, in the UK today, this is hindered by a lack of collaboration between different governmental departments who are investing independently in research into these technologies.

Could the government Chief Scientific Advisor be persuaded to encourage a more coordinated approach?

Artificial Intelligence and drone fleets

One area of advancement in undersea robotics is the application of 'artificial intelligence'. UUVs are now able to filter large streams of data, and software will become even more capable of discriminating between information that is unimportant or important for a particular purpose.

Already demonstrated is the ability of drones to operate collectively in fleets. Is this the key change in the undersea battle space that some have argued it is?

Other issues

One of the problems encountered in pursuing this research is that a lot of the information is classified. However it was felt it would be useful to have engagement with the 'Unmanned Warrior' exercise taking place in the autumn, which will have an ASW theme.

International Pugwash has groups in many different countries. It would be valuable to hold a similar workshop on emerging undersea technologies with participants from different nations. Could Russian and Chinese Pugwash be persuaded to hold related workshops?

Both submarine detection and the operation of countermeasures to avoid detection need highly skilled and trained operatives and at present there is a real lack of emerging specialists in these fields. This was felt to be in part due to the decrease in submarines generally but also to the lack of any driving factor in the absence of major wars. How can new specialists be recruited and trained before the current generation have gone from service?

One of the issues that was raised, but not discussed in detail, was the need for a global code of conduct for robotic underwater vehicles as the marine environment changes. The undersea space is vast but is now becoming populated by a vast array of different platforms, both commercial, from the oil and sea industry for example, and military. Who should be at the forefront of developing such a global code of conduct for the undersea and what should it cover?

Conclusions

Anti-submarine warfare, thanks to a range of technical developments that have been realised in hardware and software, has progressed a long way since the end of the Cold War. The continuing advance in applicable science and technology means that further developments are inevitable. Though views at the workshop differed as to how transparent the oceans are likely to become and when, it was made clearly apparent that it is becoming increasingly difficult to hide even a completely silent submarine, with some experts seeing full visibility being realised in as short a time as five years. Even if this timeline is overoptimistic, technical developments that will further increase subsea visibility are clearly to be expected in the next 20 years. Considering the long lead-time for procuring SSBNs, and the very high cost of the resulting system, it would be irresponsible not to look in depth at the implications of these advances for the viability of a future undersea platform.

It is clear that the trend is towards increasing transparency in the undersea environment. The goal of those developing marine robotics, sensing and communications techniques is to be able to map and to be able to sense the entire ocean in the next five to ten years.

This ability will impact very significantly on the ability of submarines to maintain the advantage of stealth. However, we do not know how long it will be before this advantage is fully compromised, who will get there first and whether effective and deployable countermeasures can be developed. Not all nations have the level of sophistication in submarine detection and countermeasures that the US, Russia and China do.

Advances in acoustic sensing, active low frequency sonar allied with fast, portable, high-powered computing, together with advances in optical sensing mean that even silent submarines are detectable currently.

Other sensing techniques, such as magnetic anomaly and wave detection, are likely to gain ground over the next few years, enhancing the range of detection ability further.

One of the major changes in the ability to detect and track submarines in 'real time' is this combination of advances in undersea communication with dramatic increases in processing power enabling large data transfer, advances in undersea robotics and in the capability of UUVs to employ artificial intelligence.

Another is the capability of a fleet of UUVs to operate collectively. According to a press release from the Office of Naval Research in 2015[4] such collective operations are already viable, as, for example, with the Low-Cost unmanned aerial vehicle Swarming Technology (LOCUST) program that operates in the air.

These, together with the advent of full integration of the different satellite, aerial, surface and undersea platforms, manned and unmanned, mean that, just as it is very difficult to hide on land at present, it will be very difficult to hide in the ocean in the near future.

4 According to the Office of Naval Research "LOCUST can launch swarming UAVs to autonomously overwhelm an adversary. The deployment of UAV swarms will provide Sailors and Marines a decisive tactical advantage." www.onr.navy.mil/Media-Center/Press-Releases/2015/LOCUST-low-cost-UAV-swarm-ONR.aspx

Avenues for further research

There were many questions raised by the workshop that we intend to address in the lead up to, and as part of, a major conference in September 2016. These include:

What are the practical limits to increasing the range of blue / green lasers and how would this affect the sensing and communication ability of optical techniques?

How will evolving technologies such as wave detection and anti-neutrino detection develop and interact with existing sensing technologies across the different platforms?

How might further advances in computer processing power, the range of platforms and miniaturisation of technologies further transform the effectiveness of sensing technologies? How will this, for example, influence the current trade-off between endurance and payload?

How will sensor fusion, the ability to network a whole range of sensing techniques and host platforms, change the 'game'?

How are advances in 'artificial intelligence' and the ability of UUVs to operate collectively in fleets changing the undersea battle space?

Will the bandwidths currently offered by the different undersea communications systems ever be sufficient to allow UUVs to swarm effectively?

What are the implications of the above for the deployment, strategy and modalities of submarines and SSBNs in particular?

What might be the implications of the above on states' doctrines of strategic deterrence in general?

Will the academic and scientific community be enabled to engage with the 'Unmanned Warrior' exercise taking place in the autumn?

Is there a need for a global code of conduct for the robotic underwater vehicles, and how might its development be stimulated?

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