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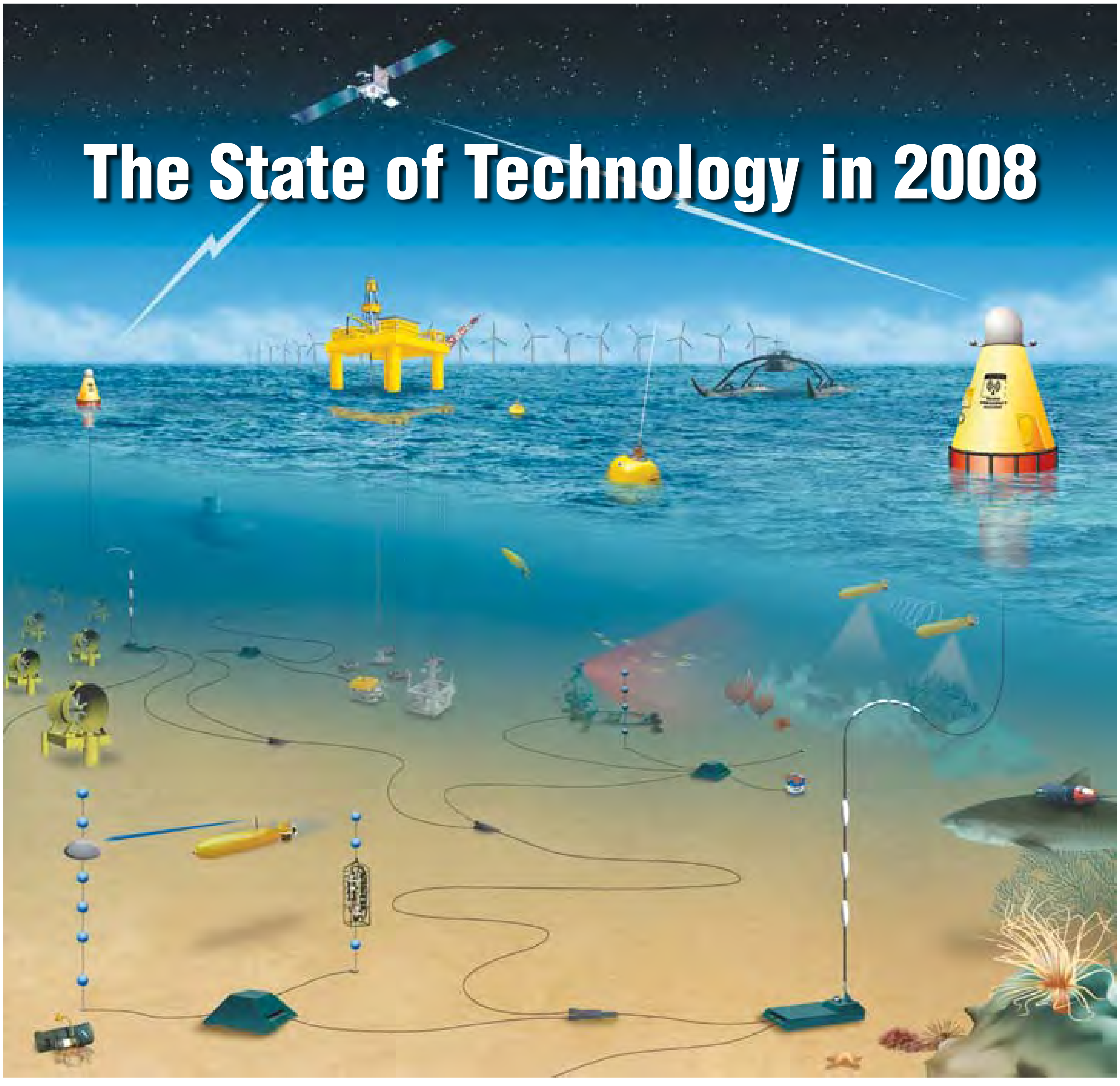

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COMMENTARY

Underwater Sonar: Plenty of New Twists to an Old Tale

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With sonar development historically being driven almost exclusively by military interests and the number of investment dollars sunk into underwater acoustics during half a century of war (both hot and cold) reaching into the billions, now (two decades later) one might be forgiven for expecting the pace of underwater acoustics technology advance to have slackened. Not a bit of it. While traditional funding sources have shifted focus, the diversity of applications and new discoveries continue to expand apace. In this commentary we explore some recent innovations and trends in interest, from vector sensors to distributed systems, from remote focusing to communications, long-range reverberation to Megahertz imaging. While the ocean still remains the last great unexplored region on Earth (the seabed being less well-mapped than both the dark side of our moon and Mars) acoustic tools are becoming more sophisticated, smaller, lighter, and more widely applied to beating back the curtains of darkness that shroud the unknown deep (and shallow) waters of our planet.

Just 40 years ago, "Computers were in glass rooms tended to by a core of monks that knew how to do the proper incantations." (Gordon Moore, co-founder of INTEL)

Time Reversal Mirror Acoustics

Time Reversal Mirror (TRM) acoustics is based on the property of the linear wave equation in that it deals only with the second derivatives of time and space and is hence invariant to the arrow of time and reversal in space. Its power lies in using the ocean as an analogue computer to calculate the channel impulse response and include it automatically in a transmission scheme to focus energy at some range and depth. A key advantage of TRM is that it requires no *a priori* knowledge of the propagation environment. Furthermore, the method is not only applicable to areas with multiple scattering, variable ocean bathymetry, and range-dependent sound speed, it positively thrives on environmental complexity. Broadband time-reversal operator decomposition (known as DORT, an acronym derived from the French name for this process) is a related processing technique that decomposes contributions to the acoustic signal from separate scatterers.

TRM has been investigated for acoustic waves in the ocean for more than a decade, but the field (excuse the pun) is now rapidly diversifying into new and exciting areas, including applications for Passive Phase Conjugation (PPC), which is a powerful means of channel characterization for communications, and Green's function estimation from the cross-correlation of ambient noise measurements. The latter technique has already been applied by Heat Light and Sound in the U.S. to sub-bottom profiling using a vertical array. In principle, only two hydrophones are required, though the field must be sampled over a very long time to adequately sample the geometric space. By combining the cross correlations of all hydrophone pairs in a vertical array, a much stronger result can be obtained, greatly reducing the required acquisition time. A drifting vertical array can then be used to determine both bathymetry and ocean sub-bottom features along its track purely from processing passively-received ambient noise in the waveguide.

TRM systems typically consist of an array of collocated source and receiver elements known as a Source Receiver Array (SRA), with perhaps a 'probe source' with one or more receivers at a separate location. Several groups have demonstrated iterative schemes by which some features of a received signal arising from particular directions can be suppressed while others are enhanced. In active sonar, a target return can be enhanced by iteratively focusing an active virtual source on the target, greatly reducing signal spreading losses by exploiting the multi-path coherence of the channel. This is a particularly powerful technique in shallow water, where active sonars are reverberation limited.

Such techniques might equally be used to do the opposite; enhance reverberation signals of interest against other features in the received signal. The Naval Research Laboratory (NRL) and NATO Undersea Research Centre (NURC) have explored how a TRM that is focused near the seafloor can be used to remotely construct a map of the azimuthal variation in bathymetry. The idea is to transmit a TRM signal from an axi-symmetric vertical array that forms a focal virtual source ring at the range of the probe source. If the bathymetry has a smooth azimuthal variation, this range will be shifted at different bearings. Backscattered reverberation is then time shifted on reception at the TRM and the round-trip time can be used to calculate the shifted focal range and hence infer bathymetric trends at each bearing. The NRL in the U.S. has acquired an SRA that they are using to test many such ideas, including echo enhancement and other properties of interest such as DORT processing to generate a directed 'searchlight' beam to probe the seabed for partially-buried mines. Similar approaches could perhaps be applied to the long-range reverberation imaging currently being investigated at MIT to image large fish stocks at long range (see later sections).

In principle, TRM shows particular promise for shallow water applications, where the propagation is complicated by strong interactions with both the surface and the bottom, leading to extended multipath echoes. Provided the channel is sufficiently stable (over the time taken for the transmission, time reversal and re-transmission of a signal), these interactions increase the effective virtual aperture of a TRM SRA. While attenuation degrades TRM effectiveness to some degree, the real enemy is the temporal coherence limitations of the ocean. Scripps Institution of Oceanography (SIO) and NURC have shown that the temporal coherence for TRM ranges from many hours for frequencies below 1 kHz in deep water to tens of minutes at 3.5 kHz. More recent results from the National University of Singapore paint a more worrying picture for shallow tropical waters, with temporal coherence down to tens of milliseconds at 8 kHz. While this appears to prohibit some uses of TRM, it does not invalidate approaches such as PCC that, together with MIMO processing, may be the best hope for reliable, high-bandwidth shallow water communications.

Sensor Technologies

Ceramics

The history of piezoelectric ceramics goes back to the beginning of underwater acoustics and would take a book to describe, yet the development story is far from over. Single crystal lead magnesium niobate/lead titanate PMN/PT compounds are showing considerable promise thanks to their high electromechanical coupling factor and high energy density. The high coupling factor (0.9) allows the usable bandwidth of a transmitter to be extended well beyond what is achievable with polycrystalline lead zirconate titanate PZT transducers. PMN/PT ceramics are also being used in the smallest vector sensors now being produced, as described in a later section.

The Armament Research & Development Establishment (ARDE) in India has developed PMN-PT ceramics for actuator and sensor applications. It has been developed and tested by the National Physical Oceanography Laboratory as part of a sonar development project. ARDE has also developed Porous Piezo-composites for hydrophones. Porous Piezo-composites are useful for hydrophone applications because of low acoustic impedance, high figure of merit, hydrostatic coefficients, and hydrostatic sensitivity.

As the interest in high-power Low-Frequency Active (LFA) sonar intensifies as the best defense against increasingly quiet anaerobic submarines, there has been a consequent increase in interest in the development of efficient low-frequency high-power transducers. Most LFA systems are very large and cannot be operated from smaller vessels or aircraft. LFA projectors are generally massive flextensional devices, typically constructed from aluminum, steel, fiberglass and graphite composites (though these are expensive). Graphite composites are desirable because of their relatively light weight for strength and high tensional stiffness. A lighter, cheaper and broader-band class of LFA transducers would be of great interest. Increased acoustic power densities have been demonstrated for LFA by slotted cylinder projectors configured with lead magnesium niobate ceramic materials. Greater LFA projector power densities translate into larger detection ranges, increased bandwidth, size, weight and cost reductions. BAE in the UK has extended the idea of slotting a cylinder to a lightweight openwork honeycomb projector shell that is claimed to increase bandwidth while reducing weight and cost.

Fibre-Optic Sensors

Fibre-optic (FO) hydrophones have been in the pipeline for three decades, ever since it was recognized that Bragg scattering in optical fibers had the potential to provide an effective solution for large-scale arrays of that could be interrogated over large distances without the various noise and loss problems associated with analogue and digital electrical signals. Both the United Kingdom and United States navies have extensively funded the development of FO sonar technology to the point that it is now deployed on submarines and as seabed arrays. The basic design of a FO hydrophone has changed little since its conception, consisting of a coil of optical fiber wound on a mandrel, interrogated using interferometric techniques. Although other approaches are being investigated, including the development of fiber-laser hydrophones, the interferometric approach remains the easiest and most efficient way to create large arrays of acoustic sensors at a distance. Such hydrophones are now being used not only by navies, but by such diverse groups as high-energy physicists (who are looking for neutrino impacts at the bottom of the ocean) and the offshore oil and gas industry, who want large arrays of seabed-mounted FO sensors allied with 3-axis geophones for geotechnical studies. This has given new impetus to the development of the sensors and the associated interrogation systems which has led to the technology being adopted for other commercial uses. It remains to find a way to reduce the size of current mandrel-wound FO sensors to smaller sizes so that the applications in high-density arrays can be realized, a goal to which many millions of dollars have been dedicated. While the 'holy grail' of a FO sensor no thicker than fishing line is as yet still out of reach, the National University of Singapore has successfully employed longitudinal noise power averaging to build very low inertia thin arrays (of 8-10 mm diameter) from strings of tiny cylindrical ceramics that can be towed by small autonomous vehicles at up to 4 knots with self-noise levels remaining below sea state 0 ambient. Having proven the application, the motivation to perfect a thin FO acoustic sensor is strong.

QinetiQ has developed a range of 'OptaMarine' FO-based surveillance networks. Physically, their FO hydrophone array consists of a lightweight cable that can be deployed from a small vessel. Based on an optical architecture of time and wavelength multiplexed interferometric hydrophones, the system is generally made up of two or more sub-arrays. In one example, the underwater section comprises two arrays each of 48 hydrophones separated by a 3 km fiber-optic link, connected to a shore station with 40 km of single-mode optical fiber. QinetiQ claims that the system self-noise levels are typically 10 dB lower than the ambient acoustic noise experienced in their sea trials with array gains close to the theoretical maximum. In principle, the use of multiple sub-arrays (none of which require electrical power) allows extended perimeters to be built over many tens of km and interrogated via a long (~ 50 km) optical fiber data link.

Thales Underwater Systems has placed a contract with a division of the QinetiQ to carry out a feasibility study on the deployment of reelable thin line towed sonar arrays for the Barracuda class submarine, a new nuclear attack submarine due to enter French service in 2017.

Vector Sensors

Directional sensors can selectively reject noise emitted from discrete interfering noise sources and localize targets, even from a single sensor. Acoustic vector sensors measure acoustic pressure and each of the three orthogonal components of particle motion in a single unit with a common center of detection. Such four-component vector sensors effectively buy up to 11 dB gain over individual omni-directional pressure sensors, in addition to resolving the port-starboard ambiguity of linear arrays. Vector sensors are normally constructed from three accelerometers plus a pressure sensor. They have been demonstrated to be effective in free field applications but there remain problems with their application to conformal flank arrays (where vibration is an issue) and in their use in towed arrays (where their current size and buoyancy are a burden). The motivation to pursue smaller vector sensors is driven by the property that vector sensors allow narrower beams to be generated with a smaller number of sensors over a smaller footprint than can be obtained from simple pressure-sensing hydrophones. This is particularly attractive for their use in towed arrays.

Small vector sensors (suitable for towed arrays) have traditionally suffered from poor signal-to-noise ratio, excessively positive buoyancy and fragility. While micro-machined sensors like the Microflown have been developed for use in air, no such design has yet appeared for underwater use. Wilcoxon Research, Inc. have taken a more traditional approach and, with the use of a new piezoelectric material (PMN-PT crystals), a patented electromechanical sensing mechanism and specialized low-noise signal amplification, they have succeeded in reducing the size of underwater vector sensors by about a factor of 2 in all directions while meeting U.S. Navy standards for towed arrays. Their new sensor is potted into a cylinder with hemispherical end caps, some 66 mm long and 36 mm in diameter; it is also neutrally buoyant in water, weighing just under 60 grams. This sensor is primed as almost a simple swap-out for existing Navy towed array sensors, although there remains considerable work to be done in the signal processing domain to develop optimal beamforming and other processing algorithms comparable to the considerable body of theory that supports current pressure-sensing array processing.

Large-Scale, Broadband and Multi-static

It is no longer news that modern sonars need to be broadband and multi-static to achieve the best results in long-range scenarios. An obvious example is the class of LFA sonars now being developed and deployed in several countries, all of which exploit both of these advantages. There have also been some non-military uses that have sprung up, sometimes from unexpected sources.

In work intended to map out the reverberation structure of the sub-bottom for improved clutter rejection in coastal long-range military sonar, MIT stumbled on a curious and very important result; that they could image large schools of fish using a bistatic active sonar. This discovery provides a means to conduct an almost instantaneous fisheries population census (and presumably also to plan more efficient capture of fish in large net operations). Continental shelf environments are traditionally monitored using line-transect methods that are slow and provide only local data, seriously undersampling the medium in both time and space. This leads to an incomplete and ambiguous record of abundance and behavior. MIT has shown that fish populations can be instantaneously imaged over thousands of square kilometers over the continental shelf and continuously monitored by simply imaging the backscattered signal of a bistatic active sonar system, as received on a horizontal line array. The technique has revealed the instantaneous horizontal structural characteristics and volatile short-term behavior of fish schools containing O(10^7) fish spread over O(10^2) km^2.

Synthetic Aperture Sonar

If not moving to multi-static, then another way to create a leap in performance over a traditional monostatic active sonar is to go to Synthetic Aperture Sonar (SAS) processing. A primary difficulty in realizing the theoretical advantages of SAS has been in estimating the sensor positions with sufficient accuracy to maintain phase coherence. Some combination of direct measurement, autofocusing based on the cross-correlation of overlapping phase centers and phase gradient autofocus is now often employed together with a dynamic model of the system (AUV plus array) often tracked by a Kalman filter to provide a robust motion estimation scheme. SAS is now maturing and has found a natural synergy with AUVs, which are less susceptible to surface motion disturbance than surface vessels. Several commercial AUV systems are coming onto the marketplace, notably the SAS AUV sonar from Thales (who are now designing their own AUV; The Asemar project includes ECA and IXSEA and the research laboratories of Ensieta, Ecole Navale, ISEN and UBO), in addition to QinetiQ's AUV-based broadband SAS being supplied to Saab Underwater Systems in Sweden; part of an underwater capability that Saab are developing for FMV, the Swedish Defense Material Administration. QinetiQ's SAS is claimed to achieve a 25 mm azimuth resolution at ranges of over 200 m from an underwater vehicle moving at up to 4 knots, with Thales' system turning in similar performance figures.

Doppler Sonar Developments

Major advances continue to drive the development of Doppler sonars for current profiling and surface wave spectra estimation, in addition to side-scan Doppler systems for surface wave, ship wake and Langmuir cell research. The development of broadband coded pulses for improved sonar precision and orthogonality, together with the development of phased array Doppler sonar is enabling the 3-D imaging of flow fields at scales from tens of mm to km and the accurate navigation of underwater vehicles using either beacons or bottom-lock tracking. Doppler sonars usually operate at relatively high frequencies, 250 kHz - 3 MHz being typical, and can therefore be made very compact, rendering them suitable for a variety of applications and easy deployment. Recent developments include moves at Benthos/Teledyne to integrate acoustic modems with ADCPs to provide a single compact unit that requires no external cabling to operate autonomously, reporting its results via orthogonal acoustic modem coded signals.

FIGURE 1

LinkQuest's 600 Micro Doppler Velocity Log.

As an example, LinkQuest's NavQuest 600 Micro Doppler Velocity Log (DVL) is perhaps the world's smallest and lightest DVL in its performance band. In its standard configuration with pressure housing it measures about 126 mm in diameter x 170 mm in length. The minimum altitude can be as low as 0.3 m, allowing users to operate much closer to the bottom than before. Applications include both deep and shallow water AUV navigation, ROV station keeping, manned submersible and diver navigation. It has a maximum range of about 100 m, a significant improvement over older systems.

COTS-Based Systems and the Impact of Increased Computational Power

Sonar system design continues to migrate from custom silicon technology with unique one-off software and firmware to COTS (commercial off-the-shelf) hardware with open source firmware and software operating environments, employing FPGAs (field-programmable gate arrays) and other intermediate customizable elements to obtain the necessary high throughput demanded by newer sonar systems. This is particularly the case for broadband sonars. The value of moving from narrow-band to broadband processing has been known for some time, but now multiple distributed COTS processors with highly configurable and capable FPGA support can finally provide the computational power required to make broadband sonars that are compact and relatively low-cost both to build and to maintain.

The cost of electronics has come down so sharply in recent years that expendable mine-destructors are now an economic option. One example is the German Navy's Seefuchs, which has been adapted by STN Atlas and Lockheed Martin as the Seafox element of its Airborne Mine Neutralization System (AMNS). It has its own acquisition, homing and classification sonar, capable of horizontal mechanical scanning, with resolution down to 0.9 degrees.

So even for military uses, the trend is increasingly to convert older systems and bring new ones to market using COTS-based subsystems. Another example is provided by the Low Cost Conformal Array (LCCA) team (with contributors from Lockheed Martin, ARL Texas, NUWC and Stanley Associates); an industry team that recently received the U.S. Navy's "Program Executive Office Integrated Warfare Systems (PEO IWS) Excellence in Engineering Award" for developing a new sail-mounted acoustic sonar system that provides enhanced tactical control for operations in coastal waters. The timeline from concept to prototype was only three years. The LCCA work adds to the Acoustic Rapid COTS Insertion (ARCI) system, which is intended to provide significant acoustic processing upgrades to the U.S. submarine fleet.

Diver Portable Sonar

Adding to the established 3D imaging sonars already proven in the marketplace and fitted to small surface vessels, AUVs and ROVs such as the Farsounder, Didson and Echoscope products, there is a new diver-operable sonar from Shark Marine that integrates a BlueView multibeam sonar into a lightweight, portable package with diver software support to give a real time image of a search area, and a means to log all underwater activity. The Navigator weighs only about 1 kg in water, including the front mounted scanning sonar. The sonar image is displayed on a 130 mm LCD screen and controlled by the diver through a GUI. The Windows XP-based unit can be operated while wearing gloves and during low visibility conditions. The LCD screen provides enough illumination to make a dive light unnecessary. Options include a WAAS GPS Receiver for shallow-water applications, digital camera, and DVL for diver navigation. It is envisioned that the Navigator will find applications in Mine Countermeasures, Underwater Archaeology, Search and Recovery, Diver Guidance and Surveillance.

FIGURE 2

The *Navigator*, a diver-operated sonar from Shark Marine.

The BlueView multibeam sonars come in two frequencies (450KHz & 900 KHz) and are modular swappable plug and play units that are finding applications with several customers such as the U.S. Navy, Port Authorities, Law Enforcement, Oil & Gas, and Dive operations. The platform flexibility and ease of integration of such COTS modular products has been proven in a wide variety of applications including boat mounted, ROV, AUV/UUV and diver hand-held systems allowing users to accomplish previously difficult or impossible missions such as inspections, detection, and navigation work in zero-visibility conditions.

Long-Range Satellite-Enabled Gateway Buoys

In another COTS leapfrogging of technology from the domestic to the military arena, Raytheon (together with RRK Technologies and Ultra Electronics Maritime Systems) is developing a gateway buoy communications system called 'Deep Siren' that includes expendable buoys 130 mm in diameter and about 1m long with antennas that receive Iridium satellite phone signals and convert them to 2 Hz coded and doppler-tolerant acoustic signals in the water that can be received and decoded up to ranges of approximately 175 nm by submarines traveling at up to 30 kts. The buoys are designed to stay afloat for up to three days and can be ejected out of a trash disposal unit so submarines can set up their own acoustic networks without the need to come to periscope depth and tow an antenna. In addition, land-based commanders can order Deep Siren gateway buoys to be air deployed in an operational area and transmit information without the usual waiting period for a patrolling submarine to come to communications depth or resorting to Ultra Low Frequency EM transmissions.

Acoustic Positioning and the Emergence of Underwater GPS

Over the last 10 years satellite navigation systems like GPS have transformed positioning and surveying in ways far outside the military uses envisioned in its design. Differential GPS (DGPS) has now consigned radio-based navigation systems to history by providing accurate positioning and tracking solutions in applications from geologic fault zone spreading to container ship offloading. While the GPS system has matured rapidly in the terrestrial and above-water arenas, there is as yet no such standard for positioning underwater. The offshore survey and construction market has grown substantially over the last 20 years and the future focus of operations in deeper waters, particularly with oil prices now exceeding $100/barrel as this commentary is written, is prompting strong renewed interest in the further development of underwater positioning systems.

The processing power required to perform signal processing and code correlation made receivers and decoders bulky and power-hungry, but now (thanks to Moore's Law) we are seeing compact DSPs and FPGAs of unprecedented power and efficiency that can easily handle the most complex spread-spectrum orthogonal coding schemes in real time. This has empowered the shift from analogue circuits and simple pulsed narrowband CW signals to much more effective orthogonal coded signals and sophisticated digital processing. Finally the benefits of orthogonality (to avoid signal interference) and pulse compression (to obtain greatly superior time resolution and signal strength from cross-correlations) are available and are being incorporated into products.

Sonardyne has developed the Fusion range of flexible hardware platforms using modern DSP technology to support both traditional "tone burst" and broadband signals. This has been extensively operated over the last two years in an extreme range of environments from the icy waters of the Grand Banks to the straits of Singapore, no mean feat when the diverse nature of both the ambient noise and propagation channel characteristics are considered.

Deepwater oil field developments require highly accurate seabed positioning. The necessary positional accuracy on the seabed is not achievable with narrowband signals in deepwater operations as the high frequencies necessary to attain the required temporal resolution are attenuated too severely over the vertical propagation range to the surface ship in deep waters. The increased precision offered by broadband signals allows positional accuracies at mid-frequencies that were previously obtainable only at extremely high frequencies.

Sonardyne has also developed a robust high-speed broadband telemetry scheme with forward error correction that is designed for real-time transfer of the relatively short data packets commonly associated with subsea navigation. In contrast to the schemes employed in many acoustic modem products, it does not require the overhead of a training sequence, which reduces the latency associated with the data. This makes it more appropriate to real-time monitoring applications such as the acoustic telemetry of gyrocompass and attitude data for navigation.

The orthogonal properties of coded broadband signal architectures largely resolves the interference problems that were common with conventional acoustic positioning systems, allowing the use of multiple simultaneous positioning operations within the same frequency band and within interference range. This has significant implications in deepwater oil field exploitation where acoustic systems have an increasingly important role to play, with both drilling and seabed installation vessels often working in the same area, with multiple ROVs using both LBL and Ultra-Short BaseLine (USBL) acoustic positioning systems, linked to atmospheric DGPS groundtruthing. This is effectively the birth of underwater GPS, without the standards that heralded the arrival of GPS and the ability to independently build GPS receivers.

Sonardyne has released their AvTrak 2 broadband acoustic navigation and communications system. A good example of functional integration, it combines the functions of transponder, transceiver and telemetry link in one low power device. It is also compatible with Sonardyne's family of LBL and USBL survey quality navigation systems. The command language allows an AUV to conduct simultaneous LBL ranging, USBL tracking via a surface vessel, and robust and high-speed telemetry both for AUV-to-vessel and for AUV-to-AUV communications.

Meanwhile Linkquest's TrackLink 5000 and 10000 systems, also based on broadband spread spectrum coding and modern DSP technology, have gained acceptance from some highly regarded clients worldwide, including NOAA, which is installing a TrackLink 10000 system on its research vessel Okeanos Explorer, capable of reaching a range of 11 km, used to track an ultra-deepwater ROV and its TMS system. Like the Sonardyne AvTrak 2, this system has an integrated acoustic modem function that can be used to send commands to and receive data from an AUV. The National Oceanography Centre (NOCS), in the UK has ordered a second TrackLink 10000 system which will be used for AUV tracking and communication. Their first system is installed on the Autosub 6000 AUV. Other clients include the University of Hawaii, which uses a TrackLink to track deepwater towed systems and the deepwater manned submersibles, Pisces V and Pisces IV.

System Integration and GUI

The power of computing has advanced so rapidly and relentlessly that it has now outstripped our ability to display and comprehend the gathered data. While data mining has a relatively long history of development, the degree of software integration and sophistication of display interfaces has not yet caught up with the real-time task of effectively conveying important information to the user. There is now a flurry of activity in the marketplace, offering modular and integrated software display packages, and some of these are now being generated by the hardware manufacturers themselves, rather than being offered by independent software engineering companies working at the margins.

SRD have developed a multibeam seabed visualization, measurement and control system for De Beers by integrating transducer arrays from its SVS3 range of real time digital sonar acquisition equipment with its own 3-D visualization software. The system will be used on De Beer's new mining vessel "Peace in Africa," which will be equipped with the largest crawler ever developed for harvesting diamond bearing material from the seabed. It generates real-time 3-D images of the underwater environment and gives the crawler's cutting depth and the volume of material being removed. This will enable De Beers to mine the seabed efficiently and reduce the risk of any over or under mining of the diamond bearing layer.

FIGURE 3

Nautilus has produced integrated 3-D images of underwater structures, linked via GPS referencing to surface images.

Kongsberg, Nautilus Marine Group & ASI Group have combined their expertise to do the first three-dimensional model of an underwater structure based on real-time data acquisition. This is the first step in developing three-dimensional modeling applications that integrate 3-D sonar returns with GPS in a way that allows underwater images to be connected to above-water images. This allows clients to see structures both above and below the waterline. All data collected below the waterline is tied into the above portion of the structure with GPS RTK.

AUV Sensor Systems

As discussed earlier in this commentary, SAS has already made its way onto AUVs, one example of how the range and complexity of available sensors for AUVs continues to expand relentlessly as the AUV technology is increasingly perceived as having matured. Furthermore, the size of competent AUVs is being reduced, moving the cost down to levels at which mass-production advantages in production cost might soon be realized. The maturation of the AUV market is revealing itself in the classic consolidation phase as this is being written, with mergers and buy-outs prevalent in the AUV marketplace.

A version of the Gavia, a man-portable AUV, has been fitted with a GeoSwath Plus 500 kHz wide swath sonar capable of collecting bathymetry data for chart use. So far it has been used to profile sea ice cover in the arctic, deployed from the APL Ice Station 2007 (APLIS07) in the Beaufort Sea approximately 300 miles North of Alaska. The ability of the GeoSwath sonar to generate a 3-D digital terrain map of the underside of the ice is a unique contribution to understanding sea ice formation and evolution. The research is aimed at corroborating airborne ice thickness measurements and investigating the accuracy in areas with complex cracking and ridging. This could have a significant impact on the accuracy of parameter estimates used in climate change modeling, which is now widely thought to be a highly non-linear process. The Gavia also has an RDI DVL and a Kearfott inertial navigation system in addition to the Gavia's standard GPS, Iridium phone, wireless link, obstacle avoidance sonar, pressure depth sensor and mini sound velocity sensor. The Gavia has a diameter of 200 mm and is fully modular, expanding to about 2.6m long in this configuration.

Diver Detection Systems

The focus of naval attention continues to burn into littoral water operations with increasing interest in protecting vulnerable assets from attack from small groups of special forces. One of the most probable platforms of attack is considered to be divers. The response from the commercial naval defense giants has been quite rapid, though to date based on low-technological risk traditional technology, rather than, for instance, a barrier formed from TRM part network or from patrolling AUVs. Given the requirement of relatively high frequency operation to resolve small targets and the range limitations this imposes, particularly in highly-reverberant and multiply-scattering shallow waters, individual units cannot be expected to cover the entire region of interest. As a result, such systems generally operate on the principle of overlapping coverage from several identical units.

Sonardyne's Sentinel is a compact self-contained diver sonar system that is relatively lightweight and can be rapidly deployed, having a sonar head 300 mm in diameter and of 400 mm height. This is a 360-degree sonar that can operate as a stand-alone portable system or as a member of a cluster of heads that are networked together to provide wide area coverage. The next step, presumably, is to allow the heads to detect each other's signals, thus forming a net of multi-static active sonars. While the system presently lacks such advanced features, it does have an automatic target detection, classification and tracking capability similar to that used in radars that removes the need for continuous manual operation. Threat warnings can be communicated over Ethernet to a host command and control centre.

QinetiQ's Cerberus is a similar, though much heavier, 360-degree active swimmer detection sonar with a range of about 800 m, again with intelligent detection, classification and tracking ability options. It is deployed and operated in much the same way as the Sonardyne Sentinel, and can be used in clusters to provide overlapping coverage. It is interesting to note that this swimmer detection sonar is the first to be used in a non-military application, having been deployed to protect the harbor entrance and waterways during the America's Cup in 2006-2007.

FIGURE 4

QinetiQ's Cerberus diver detection sonar.

The Reson SeaBat 7112 is another 360-degree system that consists of a circular array and projector that simultaneously insonifies a cylindrical volume of water up to a range of 500 m. The system can (with available options) detect, track and alert operators to the presence of divers, including those on relatively quiet rebreather units, referenced to a map of the area.

None of the three systems outlined above employ data fusion from several sensors, let alone processing backscattered data bi-statically, but this is currently being trialed by U.S. companies with involvement of the U.S. Navy and it is only a matter of time until such fully integrated systems dominate the market with their greatly enhanced abilities to repress false targets and make detections at unfavorable backscattering angles encountered by individual sensing modules.

Conclusions

The major new sonar developments making their way into the marketplace are currently being enabled by improvements in computational and sensing hardware, where the focus on shallow waters and higher resolutions are encouraging sonar sensing systems to become smaller, lighter and more easily deployed and recovered. Further into the future we can expect such systems to become more intelligent and autonomous, forming ad-hoc networks of co-operating assets. Meanwhile, upstream discoveries in signal processing and the fundamental physics of propagation are opening up new and exciting means of environmental sensing using, for example, ambient noise, that can be expected to fuel downstream applications in the future.

"The future is already here. It's just not very evenly distributed." (William Gibson)