FEATURES

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Open for Business: A New Model for Submarine Sonar

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The application of commercial off-the-shelf technology, open systems architectures and new business practice is realising major improvements in sonar processing performance, life-cycle cost and obsolescence management. Richard Scott reports

The advantages offered by commercial-off-the-shelf (COTS) information technology to military user's requirements are now well understood. Historically, military operators used bespoke computer systems, proprietary hardware and software and procured large stocks of spares for life-time support. Such an approach, which reached an apogee in the 1980s, was designed to satisfy stringent demands for real-time signal and data processing which at that time could not be delivered by the commercial/consumer electronics industry.

All that has changed. The last decade has seen military users move away from military-specified (mil-spec) systems to instead exploit the performance gains and cost efficiencies offered by COTS hardware and software originally developed for the commercial markets.

Furthermore, there is a strong desire to secure the attendant advantages offered by moving to an open systems architecture. Loosely defined as a hierarchical data processing structure which permits the straightforward connection or import of devices and programs made by multiple manufacturers, open architectures use off-the-shelf components and conform to approved standards. This means that modifications and upgrades to system functionality or performance can be accomplished at one or more layers without altering the existing equipment, procedures, and protocols at the remaining layers

This migration towards COTS and open systems architecture offers a number of pay-offs: design and development costs can be significantly reduced by avoiding the use of proprietary products and eliminating vendor 'lock-in' at all levels of the system design; regular upgrading of computer systems enables rapid additional operational capability to be inserted to meet emerging threats (harnessing the innovation offered by academia and small business, and avoiding expensive mid-life updates); and new support and sparing schedules can be introduced which are aligned with performance reliability and hardware obsolescence (analysis suggests that a refresh at an interval between three and four years offers the optimum in terms of cost effectiveness).

Submariners have been quick to pick up on the operational advantages and cost-benefits offered to combat systems, and in particular, sonar processing, by this new approach. Indeed, the US

Navy (USN) has blazed a trail with the rapid insertion of COTS products to legacy sonars across its nuclear submarine fleet.

However, it is not just the use of COTS components per se which will realise this future state. Indeed, the selection and embodiment of COTS products does not in itself constitute a truly 'open' architecture. Many existing systems, while using off-the-shelf hardware and software, still retain proprietary formats, protocols or layers which establish 'lock-in' and preclude the direct import of 'third party' applications or functionality. This is by no means the vendor-independent 'plug and play' environment which the consumer market enjoys.

Process change

What is clear is that the move to true COTS-based open architectures is not just a technology issue. Rather, it requires accompanying process and culture changes which both the customer and supplier communities must recognise and respond to. Understanding the new business model and a radically different approach to product support and configuration management are very much the keys to making this philosophical shift.

The USN's pioneering Acoustic Rapid COTS Insertion (ARCI) programme, also designated AN/BQQ-10, is the most accomplished example of COTS insertion into a submarine combat system. The programme dates back to the mid-1990s when the USN began work to explore how off-the-shelf software and signal processing could be applied to restore the 'acoustic superiority' of its submarine fleet. The service was being challenged on two fronts: at the operational level, the advantage which US submarine sonars had long enjoyed was being eroded by the improved quietening technologies being introduced to submarines worldwide; meanwhile, the acquisition community was faced with the problem of how to develop new and sustainable capability in an increasingly austere fiscal environment.

Following an internal USN operational assessment, the consultancy group MITRE Corporation was asked to lead an independent Submarine Sonar Technology Panel to assess the technology development and transition process associated with submarine acoustic signal processing.

In September 1995, the panel reported its findings and recommendations to the Director of Submarine Warfare in the Office of the Chief of Naval Operations. As well as re-engineering the capability development process for submarine sonar, MITRE recommended the replacement of legacy sonar systems with COTS-based processors and implementation of an iterative, data-driven process for incrementally fielding improved capability using Advanced Processing Builds (APBs). These provide the technology transition mechanism to engineering development from exploratory development in government and industry science and technology activities. In parallel, the US Naval Undersea Warfare Center focused on fielding a series of near-term sonar augmentation packages to address critical operational issues.

Birth of ARCI

This approach gave birth to the ARCI programme, an initiative designed to facilitate the accelerated transition of improved signal processing to legacy sonar systems, while maintaining coherence with the parallel development of the command, control, communications and intelligence (C3I) architecture for the new Virginia-class (SSN-774) submarine. Lockheed Martin, though the Undersea Warfare segment of its Maritime Systems and Sensors business, is prime contractor for the programme, which was formally established in 1996. It acts as overall integrator for each upgrade, including final assembly and test of all hardware and software improvements. It also takes responsibility for configuration control, and provides a single interface to the USN for software and hardware troubleshooting and maintenance.

However, both the USN and Lockheed Martin emphasise that ARCI is not just the application of COTS technology to solve a technical problem. Rather, it encompasses a new business model which promotes an open architecture enabling 'best of breed' technologies - including third-party applications - to be inserted at regular refresh intervals. As such, ARCI brings together skills, technology and techniques from both small and large businesses, academia, and the USN's operational and scientific communities, integrating and embodying their respective capabilities in the form of the APB.

While data-driven successes in exploratory development will transition to an APB in advanced development, the APB itself will drive hardware technology insertion into ARCI if improved performance is required. Since both pieces of software use the same hardware, fleet implementation will occur at a faster pace.

In November 1997, the first of four phases of ARCI installations occurred, and five months later the first APB was installed on a first submarine for at-sea testing (being applied to towed array processing and displays). Since then over 60 ARCI upgrades have been rolled out across legacy sonar suites on USN ballistic missile and attack submarines (including SSN-688, SSN-668I, SSN-21 and SSBN-726 class boats).

The APB effort, led by the USN's Submarine Acoustics Program Office (PMS-425) working in conjunction with the Advanced Submarine Technology Office, partitions the sonar system into 'strings' (by sensor array) to capitalise on the strengths of the developers and formulate a phased capability insertion plan (delivered through annual Technology Insertion [TI] increments). In effect it re-engineers exist-ing submarine sonar systems (AN/BSY-1, AN/BQQ-5, and AN/BQQ-6) from legacy systems to a more capable and flexible COTS-based open system architecture.

Phase I upgrades focused on towed array processing improvements for the TB-23 and TB-29 towed arrays, with Phase II introducing additional performance improvements (APB98) later in 1998. The next two increments, Phases III and IV, along with APB99, addressed processing associated with spherical and high frequency arrays along with additional towed array improvements. These were both delivered in 2000.

For these first four phases of ARCI development, Lockheed Martin developed the functionality for active and passive spherical array and high frequency passive array functions. Digital Systems Resources (DSR) - acquired by General Dynamics in September 2003 - developed towed array functions, the University of Texas Applied Research Laboratory worked on high-frequency active array functions, and Johns Hopkins University led the test programme.

An additional facet of the ARCI programme is the integration of function- ality provided by the Submarine Precision Underwater Mapping and Navigation (PUMA) upgrade. This consists of processing improvements delivered as part of APB 02 to the AN/BQQ-10 high frequency sonar (ARCI Phase IV) and AN/BCS-15 EC-19 (SSN-688 only) sonar system. This enhancement provides submarines with the capability to map the ocean floor and register geographic features, including mine-like detections, and display the map in a 3-D representation. This capability to precisely map the ocean floor allows submarines to conduct covert battlespace preparation of the sea bottom as well as minefield surveillance and avoidance.

Fleet commonality

In parallel with ARCI development, a plan has been put in place to ensure commonality and coherence across the existing US submarine fleet and the new Virginia class submarine sonar systems. This combined four distinct requirements into a common system to be developed for force-wide implementation (with platform-specific variations addressing ship interface, sensor and mechanical packaging for environmental protection).

A key enabler for ARCI is the Multi-Purpose Transportable Middleware (MTM), which facilitates migration and reuse of previous system software so as to maximise the USN's investment in legacy software. Developed by DSR, now subsumed into General Dynamics Advanced Information Systems, the MTM is a freely licensed set of software utilities that allows for high- speed data passing between the various application software modules running in the ARCI sonar system, while isolating the modules from the hardware and network protocols. This isolation allows the hardware and associated drivers to be updated without impacting the large amounts of complex application code.

DSR was also responsible for the development of the Multi-Purpose Processor (MPP) associated with ARCI. A scaleable signal processor with initial performance ranging from 320 MegaFLOPs per board expandable to over 40 GigaFLOPs per cabinet, the MPP was developed from a small business innovation research investment totalling just less than USD600,000. Its pay-off has been significant: as well as realising cost avoidance savings of nearly USD100 million in system development and procurement, the MPP has delivered 200 times the computing power at one-thirtieth the cost of the mil-spec unit it replaces.

Computing hardware, sourced from multiple commercial vendors, has been upgraded five times during the lifetime of the ARCI programme. The first hardware iteration consisted of a combination of custom and COTS VME cards to provide the necessary processing power in the limited space available on a submarine.

Hardware refresh

This initial technology baseline featured quad i860 cards, SHARC processors and a unique design signal conditioner hosted in the MPP, with HP 744 processors in the Common Display Work Station. Two SSN-688 boats, USS Augusta and USS Louisville, received this first Phase I fit.

However, several limitations with this architecture were soon discovered. The custom cards were prone to failure, were difficult to program, utilised an operating system with limited peripheral driver support, and were often subject to poor vendor support.

In a paper published in the November 2004 edition of the Journal of Defense Software Engineering, Captain Gibson Kerr, programme manager for the Submarine Acoustic Systems Program Office (PMS0401) in the US Naval Sea Systems Command's Program Executive Office for Submarines, noted: "The most important lesson learned from this implementation was that as more mainstream hardware and software components were used, fewer problems were discovered during testing, and the vendor was more likely to fix the problems.

"The first two technology insertions to the hardware baseline were performed to eliminate most of the custom VME cards in the system and to provide improved display performance. Elimination of the custom VME cards reduced system cost, improved system reliability, and made software programming easier and faster. Instead of having to code at an assembly level to discrete hardware components, the code could be written in a high-level language (typically C), and features of the COTS operating system could be used to the maximum extent. Simplifying the coding allowed the programmers to spend more time writing better code and debugging problems instead of dealing with the details of the hardware interface.

"The VME signal processors with its associated proprietary operating systems and interfaces continued to be used to meet the processing density requirements. However, the decision was made to migrate the display system from VME to a commercial workstation technology when it became apparent that there would be little vendor support for high performance graphics on VME processor boards."

After a survey of available high-end computer workstations, the decision was made to use Hewlett-Packard workstations (initially the J2240, later the J5000) and the HP-UX operating system. "The choice of this widely used COTS operating system opened the door for display development using standard Motif and Open Graphics Library software libraries," wrote Capt Kerr. "Using standard libraries and their application programming interfaces have made possible rapid updates to the displays to fix problems and implement fleet-user recommendations."

From 2000 onwards the performance levels of mainstream COTS processors was considered sufficient to perform complex signal processing applications. Since then, the technology insertion process has focused on migrating the remainder of the sonar system to mainstream COTS processors with a mainstream operating system.

"Market surveys in 2000 indicated that Intel x86 family processors would increase its domination of the server market and that the Linux operating system would become widely supported by device developers," recorded Capt Kerr. "Based on this research, the signal processing applications were shifted from VME cards to Compaq eight-way Pentium III servers running the Linux operating system."

A concurrent MPP Design Update, a co-operative development between DSR and Lockheed Martin, introduced the new Compaq 8500 servers and delivered a common cabinet design supplied by both companies in order to allow field interchangeability of servers and conventional VME chassis (8 RU modularity).

One immediate impact of this migration was a large decrease in system acquisition cost. Another benefit of using the open source Linux operating system was its broad user/developer base to help troubleshoot problems. The 2002 and 2004 technology insertions (TI02 and TI04) continued the migration to mainstream COTS hardware and software. Signal processing servers were changed from the eight-way multiprocessor servers to less expensive dual processor Intel Xeon-based servers running at higher clock speeds. In addition, the display servers were changed to dual processor Intel Xeon-based servers to reduce the number of different hardware types/operating systems present in the sonar system.

According to Capt Kerr, this delivered further gains: "Since both the display and signal processing servers now used a common hardware baseline, software development was easier because data transfer was now simpler (no more byte swapping), and a common set of device drivers could be used for both server types. Just as important, the dual processor architecture maintains the previous generation's flexibility of not having to individually program each processor."

Terra Soft Solutions was in 2003 awarded a hardware and services contract for TI02, delivering 270 Apple G4 Xserves in modified 1U chassis. For the next installation, TI04, Terra Soft introduced 64-bit Apple G5 Xserves and Yellow Dog Linux based Y-HPC (the base of the operating environment supplied by Lockheed Martin for the G5-based units, being used in the production system as well as ground-based simulation systems and trainers by ARCI).

To the maximum extent possible, ARCI system networks have migrated to Gigabit Ethernet to stay within best commercial practices and provide the most robust set of hardware and device drivers. However, the scope of change in the 2000 and 2002 technology insertions resulted in significant changes to the system network and cabinet enclosures from the previous generation. Therefore, as part of the technology insertions in 2002 and 2004, a concerted effort was made to make the system network architecture more flexible and to make the cabinet enclosures easier to upgrade during future technology insertions.

Another ARCI success factor, according to Lockheed Martin, was the early involvement of the operator community. A concept of operations group consisting of fleet sonar operators and technicians, industry representatives and academia was established at the outset of the programme to develop an overall concept of how fleet operators will view and handle the data associated with the new function.

Prototype displays are then fine-tuned during a series of APB at-sea tests on a submarine, with the results embodied into an APB. Once deployed, feedback from the fleet is incorporated to further refine the sonar operator interface and capture 'lessons learned'.

In order to secure the cost savings offered by the use of industry-standard products, the hardware must be installed in the submarine essentially unmodified. That requires a cabinet structure with a commercial rack interior that meets shock requirements, and is also capable of accommodating future technologies with minimal change. In addition, Lockheed Martin has developed the Enhanced Control Display Work Station variant of its AN/UYQ-70 console for processing and display capabilities for onboard combat and acoustic systems.

The same technological advancements that facilitate ARCI signal processing capabilities are also being directed to help meet in-service support needs. Embedded spares are designed into the system, allowing the system management function to automatically reconfigure around most signal processing hardware failures with no loss in operational capability.

Lockheed Martin, working with the USN, has established an initiative to raise reliability and guarantee operational effectiveness for a predictable operating cycle known as a Maintenance Free Operating Period (MFOP). The premise of MFOP is to eliminate the need for underway maintenance on the ARCI system by using MFOP design elements that permit maintenance to be deferred to the next port call.

In 2005, four Los Angeles-class boats were modified to enable remote interrogation for distance technical support. According to Lockheed Martin, this 24/7 'reachback' functionality met or exceeded all requirements, and is now expected to become a fleetwide feature.

The UK Ministry of Defence's (MoD's) Director of Equipment Capability (Under Water Effect) - DEC (UWE) - is championing the adoption of open architecture equipments for is nuclear submarine fleet, having been greatly impressed by the significant performance improvements to legacy USN submarine sonars delivered by the ARCI programme (a US/UK project arrangement between PMS-401 and DEC(UWE) already facilitates technical exchange). However, while the primary objective of the ARCI programme has been to expedite rapid capability upgrades, the UK's rationale for moving to 'open spiral acquisition management' is driven first and foremost by costs of ownership.

"Our motives are obsolescence management and capability sustainment," says Commander Phillip Titterton, the desk officer responsible for underwater systems in DEC(UWE). "Traditional in-service support obliges us to buy large stocks of components and spares, which carries significant up-front costs.

DeRSCI delivers

"The move to an open systems architecture offers us an opportunity to insert new technology through-life, thereby resolving obsolescence issues and driving down through-life cost. In addition, it has the additional benefit of increasing the speed and ease with which you can insert capability and refresh technology. It offers training and user benefits by providing operators with a familiar common user interface and we don't find ourselves locked into a single supplier for the lifetime of the system."

Nevertheless, Cdr Titterton acknowledges that while the technology behind an open systems architecture is now well understood, its implementation will demand a change in business process and management organisation, within both the MoD and industry.

"We need to be able to establish a smooth and steady funding line to manage the process through-life so as to be able to refresh hardware and software at regular intervals," he notes. "Within a Common Core Combat System management structure, our aspiration is to bring together EP [Equipment Programme] and STP [Short Term Plan] funds into a single flat profile funding stream. This would provide for the refresh of software every two years, and hardware on a four-year cycle.

"The other challenge is to establish an organisation appropriately configured to manage the open systems process. In this regard, DEC(UWE) is advocating the creation of a MoD-led architecture authority which would develop standards to be used by the selected systems integrator and its subsystem suppliers."

DEC(UWE)'s confidence in the savings and performance benefits offered by a migration to an open systems architecture has been given credibility by the DeRSCI (Delivery of Rapid Sonar COTS Insertion) applied research programme, begun in 2001 to examine the feasibility of open architecture sonar processing. DeRSCI has subsequen-tly evolved, with the additional involvement of the DPA and Defence Logistics Organisation (DLO), to encompass the development of a strategy to deliver an open architecture Common Core Combat System (CCCS) for the submarine flotilla.

The Defence Science and Technology Laboratory (Dstl) and UK science and technology organisation QinetiQ have taken responsibility for DeRSCI programme execution: industry participants have included ALS (towed array narrowband tracker); Array Systems Computing (towed array transient detector); Harmongram (bow array); Thales Underwater Systems Ltd (intelligent detection and tracking for bow and towed arrays); and SEA (geo-acoustic inversion process).

DeRSCI is underpinned by the development of a high-level Generic Open Architecture which defines the granularity of the system in terms of a series of application components. Generic dataflows between the application components are described in an XML Schema. The GOA also mandates a COTS infrastructure middleware to support the execution of the application components (the intention being to use COTS software in all middleware areas).

According to QinetiQ, the GOA has been specifically designed to support the easy inclusion of third-party software components. DeRSCI also has open access ports (allowing dynamic connection to other DeRSCI equipments), a multi-user graphical user interface written in Java throughout, and COTS data recording.

DeRSCI development has proceeded through a series of Technology Demonstrator (TD) testbeds used in a series of at-sea trials. The first of these, Juno, was trialled aboard a Trafalgar class boat to demonstrate functionality with a Sonar 2046 passive towed array. It was later augmented to additionally process data from the QinetiQ Crustacean thin-line towed array sonar, and again successfully trialled at sea.

In a second phase of development, designed to demonstrate the scaleability of the GOA, a TD comprising of the towed array with additional capability was demonstrated alongside the first build of a large bow array system (Pallas) using the Sonar 2074 array, and a prototype intercept sonar (Isis) using the Sonar 2082 array.

In a separate trial Juno was further modified to additionally process data from a Sonar 2054 towed array fitted to a Vanguard-class nuclear-powered ballistic missile submarine (SSBN). Subsequent sea trials demonstrated portability to a different COTS technology.

The DeRSCI series of TDs is now being positioned as the primary vehicle for demonstrating and de-risking sonar algorithm research at sea in UK Royal Navy (RN) submarines using algorithms from third-party suppliers (in addition to QinetiQ). During the development of the second TD, the passive sonar algorithm continued to mature and Juno underwent a second major capability insertion. Indeed, Dstl and QinetiQ assert that Juno now has significantly greater functionality than any other towed array fitted to an RN submarine. A further TD conducted in the second half of 2004 saw a fourth incarnation of Juno partnered with a second evolution of Pallas targeted at a very large bow array.

This same DeRSCI process has subsequently been applied to network-enabled computing. A TD known as Storm has become a focus for experimentation in underwater picture compilation functionality including data fusion, classification and target motion analysis. Storm was first trialled aboard a UK submarine during Joint Maritime Course 043 in late 2004; a second iteration of Storm went to sea in 2005.

The Storm TD will continue development as a vehicle to support the definition of a high-level architecture for the CCCS, established to deliver a common core combat system to be fitted fleetwide to RN submarines. Initially the CCCS is intended to deliver cost savings through commonality across platforms; in the longer term, incremental development and expansion of the CCCS through technology insertions should lead to a fully open CCCS with open processing data stores and networking capability.