UDT 2019 – Anti-submarine warfare (ASW) towed array capability for unmanned and small platforms

Abstract — Towed Arrays have been key Anti-Submarine Warfare (ASW) sensors for decades. Their use and operation is well understood including how large array diameters and handling systems have traditionally limited Towed Array operations to large manned platforms such as frigates and submarines. This paper looks at how newly developed Thin Line Towed Arrays (TLTAs) enable platforms such as Offshore and Inshore Patrol Vessels (OPV/IPV), Autonomous Surface Vehicles (ASV) and Unmanned Underwater Vehicles (UUV) to provide game-changing ASW capability. Systems Engineering & Assessment (SEA) Limited has developed a scalable TLTA, with its current KraitArray variant providing a configurable connectorised digital Towed Array with up to 192 acoustic channels and up to 150m in length. During the past 10 years of development, SEA has integrated KraitArray onto multiple platforms, gaining industry leading experience in the area. This paper covers the challenges and lessons learned from miniaturising Towed Array technology and the use the latest Commercial-Off-The-Shelf (COTS) technology to reduce array size and power. This includes design of the KraitArray's key components. Potential applications for KraitArray deployed as an ASW sensor from small and/or autonomous platforms are discussed, and how ASW operations and capabilities can be increased and improved for significantly lower costs than that of traditional Towed Array systems. Examples will be provided from KraitArray's use in Unmanned Warrior 2016 to successfully detect and track a submarine, and other trials held with a wide variety of vessel types. This will demonstrate the maturity of remote and small footprint ASW systems and their capabilities, as well as highlight the future challenges such as Concept of Operations (CONOPs)

1 Towed Array History

Towed Arrays have been common place amongst the major navies for many decades and are a key sensor in a naval vessel's capability in the detection, tracking and classification of other vessels. They provide numerous advantages over hull mounted sonars such as variable depth, lower frequency beamforming, greater detection ranges, and reduction in the effect of own ships noise. These advantages are mainly due to the length of a Towed Array's acoustic aperture being longer than the towing vessel and positioned at the end of a long tow cable.

Traditional Towed Arrays are large oil filled Polyvinyl Chloride (PVC) or Polyurethane (PU) hoses which can exceed 600m in length and measure between 30mm and 90mm in diameter. Contained within the hose are hydrophones and Non-Acoustic Sensors (NAS) to provide acoustic, heading and temperature sensing. The weight and volume of traditional Towed Arrays requires large manned vessels to tow an array along with bulky handling systems, which tends to lead to bespoke ship design. This has previously limited Towed Array operations to vessels such as Frigates and conventional Submarines, which are costly assets to purchase and operate, particularly for the required duration associated with ASW deployments.

Fig. 1. Traditional Large Scale Towed Array

2 KraitArray

In 2010, Systems Engineering and Assessment (SEA) Limited developed its first generation low power, configurable digital Thin Line Towed Array (TLTA) named KraitArray. KraitArray's small 16mm diameter and up to 50m length results in a considerable reduction in weight and volume, enabling smaller vessels such as Offshore and Inshore Patrol Vessels (OPV/IPV) and Unmanned Vessels to host and deploy an ASW Towed Array capability.

The original KraitArray contains up to 32 low power, low noise hydrophones, each digitised by a bespoke small scale, low power, high performance digitisation system known as the Micro Digital Acquisition and Source System (μDASS). To aid array shape estimation and environmental sensing, up to eight sensors known as the Micro Non-Acoustic Sensor (μNAS) can be fitted to

KraitArray to provide heading, pitch, roll, temperature and depth measurements.

Fig. 2. KraitArray v1.0 Thin Line Array

Since KraitArray's launch in 2010 it has been integrated with and operated from a variety of vessels including small research vessels, rigid inflatable's and more than five types of unmanned vessel.

Building upon the success of the first generation KraitArray, in 2018 SEA developed and launched KraitArray Version 2 (v2) which provides the user with up to 192 hydrophones and an increased acoustic aperture length of up to 150m. These advancements increase the overall detection range of KraitArray v2 and the ability to listen for and localise lower frequency targets compared to that of the first generation KraitArray.

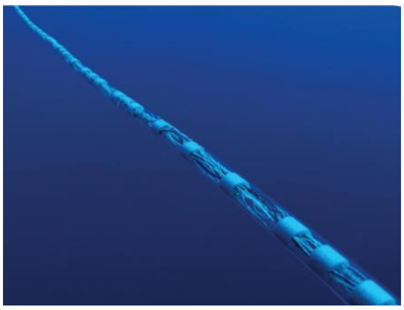

Fig. 3. KraitArray

3 KraitArray Design Challenges

KraitArray's small diameter minimizes the physical system footprint, which in turn reduces or removes the necessity for large handling systems while also reducing hydrodynamic drag forces. Many design challenges were faced during the development of both generations of KraitArray, however through the use of Commercial-off-the-Shelf (COTS) technology SEA has overcome electrical, mechanical and acoustic engineering challenges. The Strain Member, Hydrophone, Digitisation System and Module Interconnect all posed significant challenges during KraitArray's design.

3.1 Strain Member

A Towed Array Strain Member provides the mechanical backbone which extends the length of the array and allows precise mounting of sensors and components. Due to the hydrodynamic drag forces induced during towing which are transferred via the hose and internal components to the strain member, the strain member requires high tensile strength and low elasticity. Typical hydrodynamic drag forces verses tow speed for a series or representative Towed Array diameters of 150m are shown in Fig 4.

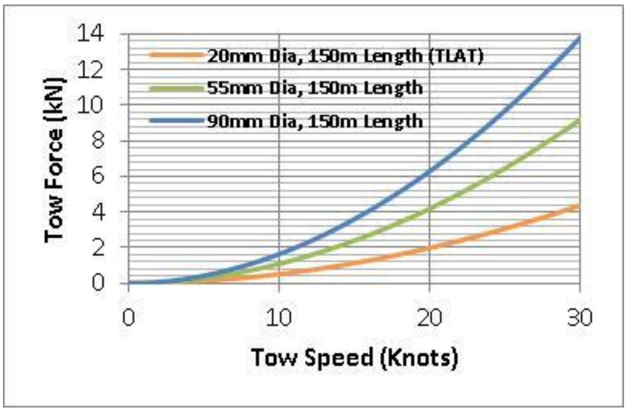

Fig. 4. Indicative Towed Array Hydrodynamic Drag

ASW operations are performed at low tow speeds by the towing vessel to minimize self-noise and avoid detection; therefore there is minimal difference in hydrodynamic drag force. At high speeds the hydrodynamic forces transferred to the Towed Array Strain Member and subsequently the tow vessels point of tow increase significantly. An array capable of only low tow speeds would impact the towing vessels manoeuvrability, particularly when evasive manoeuvres are required. Testing and selection of KraitArray's strain member has led to the use of a high tensile strength, low creep material which fits within the small space envelope of the hose, ensuring KraitArray can survive greater than 28 knot tow speeds it may be subjected to during deployment.

3.2 Hydrophone

A hydrophone is the primary sensor in a Towed Array, which when multiples are configured in a straight line enables acoustic beamforming by the sonar processing system. Typical line array hydrophones contain large piezoelectric ceramic devices so as to provide high sensitivity and minimize any pre-amplifier electrical gain requirements. A low pre-amplifier gain is driven by the necessity for low pre-amplifier electrical self-noise to ensure the hydrophone pre-amplified output is lower than the equivalent ambient acoustic noise.

In order to minimise KraitArray hose diameter, SEA have developed a new low noise, high gain pre-amplifier to allow the piezoelectric ceramic size reduction. Dimension restrictions challenged both the electronic pre-amplifier and associated mechanical mounting arrangement design. Through the use of the latest 3D printing technology and leading electronic design capabilities, an acceleration cancelled hydrophone with attached miniaturised low-power low-noise pre-amplifier has been designed.

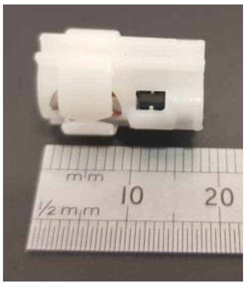

Fig. 5. KraitArray v2 Hydrophone

During KraitArray v2 development the pre-amplifier design was revisited to reduce the noise floor to below Knudsen Sea State Zero and include a Built-In-Test (BIT) function to confirm pre-amplifier functionality when installed in the array.

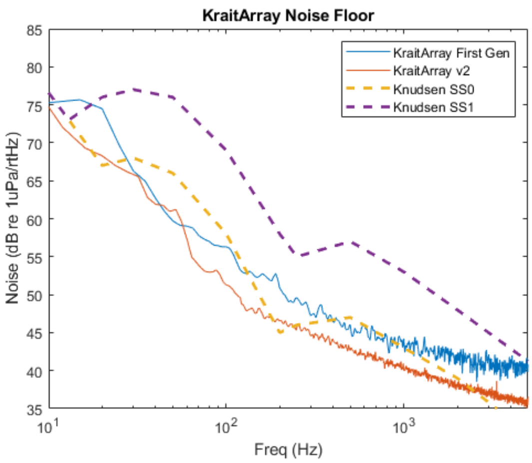

Fig. 6. KraitArray Hydrophone Noise Floor

3.3 Digitisation System

An array digitisation system housed within a Towed Array provides many advantages such as signal multiplexing with reduced noise susceptibility, and reduced number of electrical conductors, aiding overall array performance and the ability to package electronics and wiring inside a small diameter hose.

In KraitArray first generation the µDASS was located at the head of the array due to it's larger than 16mm diameter. The low power digitisation system provided 32 simultaneously sampled 24bit Analogue-to-Digital Converter (ADC) channels with 120dB dynamic range. This allowed for up to 32 hydrophones to be installed in the array with the digitised data output over the User Datagram Protocol (UDP) Ethernet interface, allowing the user to easily integrate KraitArray into new or existing sonar systems.

Fig. 7. KraitArray µDASS

Locating a digitisation system at one end of an array means any additional hydrophones requires extra signal cables, which in turn increases the number of electrical conductors within an already limited space envelope. It also means any inter-module electromechanical connectors require increased contacts which inevitability increases the connector dimensions.

KraitArray v2 addresses these limitations by distributing a 24bit simultaneous sampled, 120dB dynamic range digital sampling system within the KraitArray hose. A series of digitisation nodes connected to a common digital backbone running throughout the length of the array allows up to 192 hydrophones to be distributed and sampled over up to 150m..

Developing a low power small scale digitisation system posed many challenges, mainly with regard to COTS electronic components. While the advent of smart phones and portable electronics has focused the electronics industry to develop smaller and more power efficient electronic components, some devices such as the ADCs do not provide the level of accuracy required for a high end Towed Array digitisation system. It is only when the advancements in Printed Circuit Board (PCB) design and manufacturing techniques are coupled with the electronic components advancements that it becomes possible to package such a high performance digitisation system into a small space envelope.

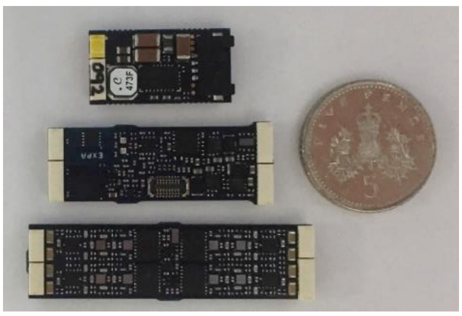

Fig. 8. KraitArray v2 Digitisation System

3.4 Module Connector

To manufacture arrays longer than 50m an array must be manufactured in sections, introducing a requirement for a watertight electromechanical connector. Increasing the length of an array and its acoustic aperture allows for increased hydrophone counts, which in turn increases the array's Directivity Index (DI) as well as the ability for lower frequency beams to be created in the sonar processing, resulting in greater detection ranges of the Towed Array system.

Distribution of the KraitArray v2 digitisation system and the introduction of a digital backbone mean the required number of electrical connections is minimised and remains fixed as the number of hydrophones and modules increase. This has led to SEA developing a bespoke watertight connector rated to 500m depth which is scalable down to 16mm diameter to match the array hose diameter, creating a seamless interconnect between KraitArray modules.

Fig. 9. KraitArray Inter-module Connector

The connector development posed many electrical and mechanical challenges to ensure all required signals and power are passed from module to module as well as surviving the tow loads likely to be seen during deployment. Modern mechanical design tools such as 3D Computer Aided Design (CAD), Finite Element Analysis (FEA) and Additive Layer Manufacture (ALM) for rapid prototyping of metallic parts permitted a successful design and testing. The KraitArray Inter-module connector supports up to 32 electrical connections at 1.5 amps per pin, tow loads up to 4kN and tool less polarised mating and de-mating.

4 TLTAs for Small Vessel Operation

Historically, naval vessels were designed to perform specific roles from the time of their inception. With reduced budgets, asymmetrical warfare and the need for flexible collaboration, this paradigm is becoming more the exception rather than the rule.

Even first tier Blue Water navies are now looking for ways to exploit vessels of opportunity in order to provide force multiplication and demonstrate sound financial management.

A vessel dedicated to ASW will always provide the best standalone performance. With a low acoustic signature, the most advanced active/passive submarine hunting sonars coupled with a crew trained for the mission this is an inescapable truth.

Leveraging the dramatic size and weight reduction of the TLTA to support ASW from vessels such as OPVs and IPVs is the concept behind the Krait Defence System (KDS) currently being produced by SEA. Not only does this solution enable ASW operations from smaller vessels, its modular footprint and simple installation allows for cross-decking, enabling navies to further enhance the return on investment by releasing the equipment when vessels enter planned maintenance periods.

The KDS concept is best illustrated diagrammatically as shown in Fig 9. The KraitArray Thin Line Array is offered as a solution agnostic sensor and is utilised in various static and dynamic configurations by various vendors. Using its wealth of sonar systems experience SEA has taken its own sensor and developed a scalable end-to-end ASW solution. KraitSense offers a passive array, handling system and inboard terminal unit with associated passive detection software.

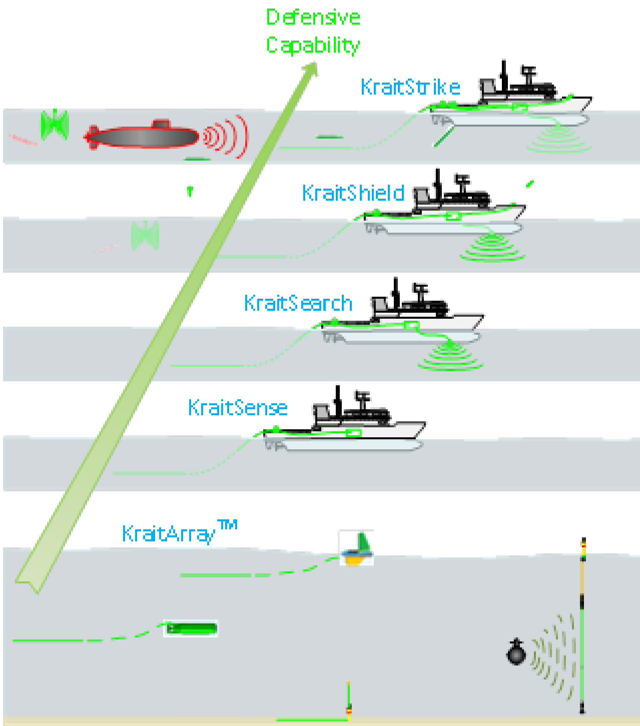

Fig. 10. Illustrated KDS Concept

KraitSearch augments the passive array with an active capability by incorporating a high frequency section within the Array and adding a hull mounted acoustic projector. The associated terminal unit is upgraded to incorporate waveform generation and amplification, supported by an updated software suite incorporating active detection algorithms.

KraitShield offers navies the ability to integrate a torpedo decoy launcher into the system. The launcher is payload agnostic enabling either SEA's in-house torpedo decoy to be utilised or expendable stores from other manufacturers.

KraitStrike provides the ultimate ship-borne submarine deterrent, a lightweight torpedo launcher. This launcher is payload agnostic launcher and has been provided by SEA in its standalone configuration to multiple navies across the globe.

As discussed previously an ASW specific vessel will have a crew trained in hunting submarines together with the most advanced sonar suites. To allow a vessel of opportunity to perform this role successfully will inevitably require additional training. However, this can be augmented by a modern, well designed software interface providing users with intuitive screens and associated controls. SEA has considered this from the inception of the KDS software enabling a system to be provided that is both powerful and intuitive to use. Based on modern operating systems and design concepts the system has already been run within a 3rd party virtualised environment.

5 Unmanned Applications

As an increasing number of nations are investing in submarine capabilities, the predicted spending on unmanned ASW assets to counter emerging threats is expected to exceed US $3bn in the next 10 years. KraitArray has been specifically designed to meet the demands of unmanned ASW systems and is therefore key to the operation of these assets. Since 2014 KraitArray has been integrated and successfully towed from numerous unmanned vessels including ASV C-Enduro, AutoNaut, Thales Halcyon, BAE Systems P950 Autonomous RHIB Demonstrator and Liquid Robotics Wave Glider.

The most notable unmanned ASW application of KraitArray to date was during the Royal Navy led Unmanned Warrior 2016 exercise where four Wave Gliders towing KraitArray's were deployed and successfully detected and tracked a live manned submarine. Since Unmanned Warrior 2016, Boeing Defence UK has further developed a Wave Glider ASW solution, MEDUSA, to include a longer acoustic aperture array using KraitArray v2. MEDUSA trials performed at the British Underwater Test and Evaluation Centre range at the end of 2018 saw the system successfully detect, report and track a simulated submarine target in real time, with results providing close correlation with performance modelling. The trials demonstrate maturity of the MEDUSA Wave Glider and KraitArray solution and how the system can be used for effective ASW, littoral water and coastline protection operations.

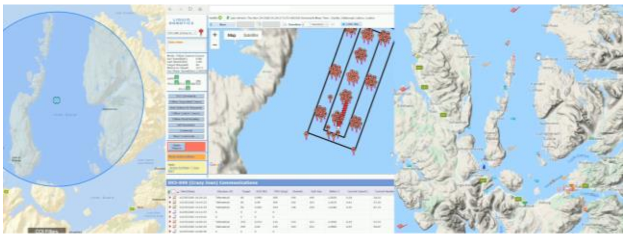

Fig. 11. MEDUSA Wave Glider Trials Area

Fig. 12. MEDUSA Wave Glider Post Deployment

KraitArray's low hydrodynamic drag, low electrical power requirements and small physical footprint means most conventional or unmanned vessels can tow and operate KraitArray. ASW Unmanned System advantages include:

- Long endurance for prolonged and persistent surveillance;
- Low purchase and operational cost compared to manned assets;
- Removes personnel from the operational environment, reducing or removing the risk to life;
- Covert due to little or no acoustic and/or radar signature;
- Short or no tow cable required, simplifying deployment and recovery;
- Multiple unmanned vessels integrated to work together over a large area;
- Used as nodes within a Multistatic scenario;
- Host other remote sensors in addition to a towed array.

Developing and operating unmanned ASW systems introduces a new set of challenges in ASW sensing. The most significant challenge is the gathering, transfer, processing and analysis of sonar data, and the security of processing algorithms and data on an unprotected/unarmed ASW platform. Traditional ASW sonar processing systems are located on a manned platform and operated by highly trained sonar operators. The trained eye/ear of a sonar operator and their ability to determine a legitimate threat amongst a complex operating environment ensures false reporting is minimized and the target classification confidence levels are maximized. To achieve the same level of performance from an unmanned system, a high bandwidth data link is required to transfer all sensor data from the platform to a remotely positioned operator. Such data links are either unavailable or extremely costly and power consuming. The data link also creates an electromagnetic signature, detectable by enemy forces thereby giving up the systems location and negating the covertness desired from an unmanned system.

One method of overcoming the above challenge would be to embed automated sonar processing on the unmanned platform, however the level or performance offered by current and near future automated sonar processing is inferior to that of a trained sonar operator. Methods of minimizing data link requirements, on-board sonar processing and target detection confidence levels are being worked on by numerous companies and institutions however more is required in the immediate future to prove and validate their performance. New Concepts of Operations (CONOPs) should also be considered such as how unmanned platforms may act as continuous sensors to inform and target operations of manned air and naval assets, which would increase the efficiency of these mort costly platforms. The MEDUSA programme undertaken with Boeing Defence UK and Kaon Ltd has demonstrated some of the functionality required.

6 Conclusion

It should be evident from the topics discussed in this paper that TLTA has matured significantly in the past 10 years, enabling smaller and unmanned vessels to perform ASW operations that were traditionally only performed by larger manned vessels.

The successful self-funded development of KraitArray has mostly been made possible due to advancements in modern electronic and mechanical design tools and the ability to miniaturize, visualise and rapid prototype designs in 3D. It is also due to technology drivers such as smart phones and portable electronics that electronic components have miniaturized and PCB manufacturing techniques have advanced significantly. This has enabled array electronics to be packaged with extremely small space constraints. Development by SEA continues to further develop and improve the capabilities and performance of KraitArray.

While the array technology has evolved, the end manned and unmanned systems and solutions are still in the early days of development and evolution. KDS addresses the immediate issues for manned vessels however future work is still required to maximise the systems potential such as reduction of own ships noise, training of operators and maintainers, and developing CONOPs.

For unmanned applications the challenges are mostly focused around data transfer and processing, along with system CONOPs. Development and trials of KraitArray has demonstrated on many occasions that unmanned vessels can operate autonomously with a TLTA for long periods. With a sensor and multiple unmanned platforms available, it is now the responsibility of system developers and end users to establish an end solution and its operation. It is easy to approach the challenge with a traditional ASW operations and processing mindset but it is of the opinion of the author that a new approach is needed, specifically with regard to CONOPs and the integration of unmanned systems with more traditional assets. Industry is currently working on solutions to enable navies to adopt unmanned ASW assets but more in-water trials and scenarios are required to develop and refine CONOPs.

Author Biographies

Chris Tucker - Product Technical Authority for KraitArray at SEA. Working for more than 14 years in the defence and towed array industry, Chris has worked on the design, development and operation of KraitArray since its conception in 2010.

Darren Puckey - KDS & Sonar Technical Authority, at SEA. Chartered Engineer with over 20 years' experience in the specification, design, development, integration and test of complex sonar and data communications systems for naval applications.