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Session: Using Commercial Technologies in Defence Products

Theatre: Exploitation of Commercial Technologies

Future Underwater Enablers; learning from other operators within the marine sector

Abstract — The underwater environment is a complex and challenging operational space. In defence there a challenging set of threats to face that require complex systems to overcome. This statement is true today, as it has been in the past, but in the future is expected these challenges and complexities will be even more abstract with the range of off-board systems and in addition to major platforms in use in the defence sector. Understanding the complex environment, in particular operations at or around the seabed, is an area under large investment and utilisation outside of the defence sector.

What can defence learn from the non-defence (marine) sector? What technologies exist; what technology is being researched; how are similarly complex engineering challenges being scoped and solved? It can be observed that sectors outside of defence such as oil & gas or the marine scientific community are also overcoming their problems through the use of autonomous and unmanned platforms forming part of a complementary set of off-board systems.

1 Purpose

This paper is collaboration between BAE Systems Submarines and Sonardyne International, a leading technology and solution business predominantly within the non-defence sector. This paper will examine the future trends and challenges associated with the various enablers for this domain such as platforms (incl. autonomous), sensors, navigation, positioning, communications and energy systems. Exploring a vision for the underwater battlespace in the 2035 – 2050 timeframe and what likely technology transfer or developments exist in the non-defence sectors that will develop in the near term, before 2025 and those that could be in-use in the future.

This paper will also explore the wider enterprise challenges, not just technology or solutions; analysing the industrial skills and collaboration opportunities between sectors including synergies such as manufacturing, training, support or test & evaluation facilities. In addition, an outline approach to the use of seabed infrastructure shall be explored including where and how the non-defence sector is protecting strategic assets and techniques for protecting other types of national infrastructure.

2 Introduction

This paper is a cross-cutting paper across a number of this year's themes for UDT. However the main theme is to understand the commercial 'non-defence' sector and how this could be exploited. The maritime region and defence operations in and around Scandinavia have a rich industry and technology base in the non-defence sector, specifically oil & gas. This paper is therefore particularly pertinent to the location and interests of the defence operators around Scandinavia.

3 Approach

A joint investigation by BAE Systems Submarines and Sonardyne International, the approach to the paper started with a set of meetings to understand the possible synergies between the two 'sectors' before conducting research into, primarily, the non-defence sector.

4 Sector Overview & Analysis

4.1 The underwater defence sector

The defence sector in the underwater domain can be described as any platform or system that enables military capability[a] to be delivered from within, into or outside of the underwater environment. Not all of this capability operates within the underwater battlespace which is both temporal and spatial in terms of the scale of the battlespace with reference to a military campaign ie. defence may use systems in peacetime or for benign data collection in the environment. The systems that may be considered as enablers to achieving such underwater capability cover everything 'from seabed to space' in order to achieve overall situational awareness and command & control (C2). However, at the core of underwater capability is the submarine. It is argued in many underwater defence and technology conferences that the future nuclear submarine, and indeed future

[a] Achieving the right effect, in the right place, at the right time. Capability comprises not just technology or systems but the policy, people, training and tools to deliver it

underwater warfare will be information rich and dominated by a range of autonomous and distributed systems, namely, UUVs, USVs and potentially supporting Seabed Infrastructure – this is expected to be prevalent on the 2035-2050 timeframe. In the non-defence sector many of these systems are being utilised today.

4.2 The underwater non-defence sector

Hereafter referred to as the 'marine sector' describes broadly the application of technology for research or operational programmes in the following areas:

- Oil & Gas and Renewables/Energy (both including supporting offshore installations in the subsea[b]), Exploration and Survey, Marine/Ocean Science

The marine sector operates systems within and on top of the underwater environment, primarily ships and submersibles, tethered ROVs and subsea/seabed infrastructure. Many challenges and technology solutions are similar to defence albeit defence has more challenging operational constraints most primarily the need to operate in an underwater battlespace and the operational mission security that entails. Like defence, this marine sector operates systems in the underwater environment for extended periods of time, 24/7 in fact. The marine sector is fully equipped with the people and supporting infrastructure to test and evaluate, manufacture and support some of these systems. Many new systems are being developed to help automate and simplify marine operations, in particular the more challenging operations where persistent monitoring is required. This is especially true for seabed and critical infrastructure operations. In this (seabed) operational area and in surface delivered survey operations is where it is observed that autonomous systems are being evaluated more significantly. The marine sector has arguably the same challenges for technology integration that defence does.

Challenges for Integration – Integration is not simply about the physical or control aspects. Some of this can be addressed today, but must consider the longer-term systematic challenges. Probably the most important challenge will be at the enterprise level. This covers:

- Systems architecture understanding and development;
- Software development; modelling and simulation, training and distributed control systems;
- Security accreditation for new systems across the underwater domain;
- Unmanned systems and autonomous technologies skills development;
- Infrastructure to support through-life management of systems;
- Advanced manufacturing and in-service support solutions;
- Platform / payload agnostic integration;
- Energy harvesting, docking and 'garaging';
- Sensing and response to seabed infrastructure faults;
- Seabed intervention and repair;

4.3 Cross-Sector Analysis

It can be extrapolated that certain operations in the underwater battlespace will likely see demand for increased capability that requires pull-through from said alternate sector. As described in the sector overview, there are a number of similarities between the sectors operating in a common environment with similar platforms, operations and technical or environmental challenges. A deliberately simplified set of comparisons are summarised in the tables below which should indicate the commonality between the sectors. The next section will look into more detail at some example programmes and technologies in the marine sector.

Table 1. Cross-Sector comparison of typical underwater Platforms.

Platforms	Defence	Marine
Submarines	Y	N
Surface Ships	Y	Y
Aircraft	Y	N[c]
Satellites	Y	Y
Remote Vehicles	Y	Y
Autonomous Vehicles	Y	Y
Seabed Infra	Y	Y

Table 2. Cross-Sector comparison of typical underwater Operations.

Operations	Defence	Marine
Covert surveillance underwater	Y	N
Covert surveillance	Y	N

[b] Whilst the different industry areas within non-defence as described can be broadly understood, the term 'subsea' is often used to describe this sector also. However, subsea is also often used to deliberately describe the seabed and operations into or below the seabed itself, hence, marine was chosen as a more generic phrase to describe the non-defence sector as a whole

[c] Although aircraft are utilised in some marine operations, such as LIDAR sensing, aircraft are not considered a platform type used regularly within this sector

above water		
Environment Assessment	Y	Y
Geospatial Assessment	Y	Y
Under Ice & Arctic	Y	Y
Seabed	Y	Y

Table 3. Cross-Sector comparison of typical underwater Challenges.

Challenges	Defence	Marine
Data Integrity	Y	Y
Asset Integrity	Y	Y
Operational Safety	Y	Y
Operational Security	Y	N[d]
Ambient Noise	Y	Y
Environment Assessment	Y	Y
Marine Mammals	Y	Y
Marine Fouling	Y	Y
Manned / Unmanned Teaming	Y	Y
Remote Sensing	Y	Y
Comms	Y	Y

5 Results & Discussion

The previous section outlined the differences between the two sectors under review. This section will detail a broad over-view of various programmes and technologies.

5.1 Offshore Industry (marine sector) Overview

The commercial offshore industry is vast and encompasses many different sectors that make up the entirety of what has been referred to in this paper as the 'marine sector'. This primarily includes Oil & Gas, Renewables (Energy), Aquaculture, Marine/Ocean Science etc. All of these sectors are utilising advance technology to reduce the cost and risk of conducting work offshore. The Oil & Gas sector can be further broken down into Exploration, Survey, Construction, Production and Decommissioning, with the cycle time of subsea assets being greater than 20 years.

On the exploration side there is a drive to have small autonomous four component (4C) seismic sensing vehicles that can fly to a location, sit on the seabed for the period of the seismic survey and then fly back to the mother vessel or recovery system. Alternative seismic and subsidence monitoring system are being deployed that will remain on the seabed for many years, continuously monitoring passive seismic and other sensors of interest. As it is important not to disturb the seabed nodes the data is off-loaded periodically using extremely high bandwidth non-contact optical communications capability. This can provide data rates in excess of 600Mbps over distances of 5m.

Survey tasks are being conducted using AUVs rather than a vessel and an ROV, however many of the construction tasks still require work class ROVs and large support vessel as they are often lowering large pieces of infrastructure to the seabed. Again, throughout the survey and construction phase subsea navigation and communications is critical to ensure safe and reliable operations. The assets need to be monitored to fully understand the operational life, start-up effects, minimise erosion and fatigue to ensure efficient use. These monitoring systems are often attached to the pipes or valve control asset to allow semi-real-time vibration analysis, displacement, pressure, temperature and well integrity management.

The Oil & Gas sector are making technologically advanced vision statements, like having all subsea infrastructure inspection tasks being conducted using field resident ROV/AUVs with shore side control by 2025. To achieve this, seabed resident inspection and light intervention semi-autonomous Remotely Operated Vehicles (ROVs) will be permanently deployed in a subsea garage next to critical infrastructure. Using the latest navigation and communication technologies the vehicle will be able to self-navigate to a point of interest and then provide real-time control and visual feedback to an operator on-shore.

Other industries are changing, with large scale fish farms are being deployed further offshore where there is less pollution and where the feed is less likely to affect the seabed as it is more dispersed. These assets are utilising the lessons learnt from the Oil & Gas sector to minimise people and cost whilst operating in a harsh environment. Likewise, the renewable energy sector is being pushed further offshore thereby requiring different deployment methods, instead of being fixed onto mono piles, the wind farms will be floating. This requires suitable, surveying for anchoring and then monitoring of the anchor mooring lines to ensure the safe and reliable installation and operation.

[d] This is marked N, for simplicity, this is because of the classification of operations and data are driven differently in comparison to defence. There isn't a need to be highly covert in marine operations nor indeed is there a need to manage signatures of assets in the same way Defence needs to. Management of active acoustics (wrt marine mammal mitigation) will however be common in both sectors and to some degree the Marine sector is having to protect information but not to the level of security and cryptographic techniques in defence.

When considering all of the technological advances that are happening they are all reliant on the ability to communicate information. Currently this bandwidth requirement is high as humans like visual images of the infrastructure that is being inspected or manipulated. With key infrastructure having free-space optical communication it is possible today to have low latency wireless vehicle control and video feedback, allowing wireless remote control of subsea vehicles.

However, as systems become more advanced and autonomous the amount of information is likely to reduce as on-board Artificial Intelligence (AI) will be making cognitive decisions thereby reducing the amount of information that needs to be fed back to the control centre. Even though the communication bandwidth requirements for particular systems may reduce the overall bandwidth requirements will still increase as the connectivity requirements of intelligent sensors and near real-time monitoring is used to drive efficiencies. This is similar to the drive in the retail sector with the Internet of Things (IoT) and the requirement to have 'things' connected. As more information is gathered this data can be processed in different ways to provide predictions on fatigue life of infrastructure, changes to operational efficiencies etc.

5.2 Industrial Bodies

There are various societies and government funded bodies that are focused on improving our knowledge of the marine environment. Some are aligned to the Oil & Gas sector, whereas many are focused on oceanographic research to make sense of the changing oceans and the likely impact on human wellbeing and wealth.

The Oil and Gas Innovation Centre (OGIC) and Oil and Gas Technology Centre (OGTC) are Scottish Government Fund Innovation partnerships that are industry leading. The OGIC takes early Technology Readiness Level (TRL2-6) idea and aligning the technical disciplines with Scottish universities that have research expertise to progress the idea through to a prototype or concept systems. The OGTC can then help to transform concepts through to working products or systems. The key drivers are to, stimulate, deliver and accelerate innovation in key strategic areas.

Similarly, and more broadly across the marine sector, the National Oceanography Centre (NOC) is a world-leading hub for advanced R&D having strategic goals to deliver high quality science and technological advances.

Not an industrial body or a leading centre such as The NOC, 'The ORCA Hub' is an ambitious £36M programme aimed at addressing the offshore energy industry’s vision for a complete and autonomous energy field. The Hub was launched as part of the UK Government’s £84M R&D funding on robotics and AI for extreme environments and is led by Heriot-Watt University and the University of Edinburgh. The Hub brings together experts from over 30 industry partners to create a multi-disciplinary consortium with unique expertise in: Subsea, ground and aerial robotics, Human-machine interaction, Innovative sensors for non-destructive evaluation and low-cost sensor networks and asset management and certification.

Deepstar is Research & Development collaboration between oil companies, vendors, regulators and academic/research institutes started in 1991. It's vision is a global forum to execute development and adoption of deepwater technology projects. Providing value through leveraging financial and technical resources to deliver technology needs and build deepwater technical competency. The strategic technology developments are aligned with business needs, allow the transfer and application of said technology to deepwater assets, whilst gaining acceptance of deepwater technologies by industry, standards organisations and regulators

It’s clear that the focus of many of the government and industry lead initiatives have the same themes of: autonomy, AI, robotics and asset integrity, all requiring reliable and robust communications through the medium.

Other leading industrial voices and societies are helping to coordinate standards and working practices, amongst many other areas of development, through special interest and working groups. Principally, in the UK, The Society of Maritime Industries and globally, although headquartered in the UK, The Society of Underwater Technology are providing this coordination and to some extent is starting to bridge the overlap between the two sectors discussed in this paper. This is clearly only a UK centric view and indeed, globally, but certainly in Scandinavian, Canadian, US and Arctic regions, there are many other similar industrial bodies whose knowledge and access to skills and technologies could be utilised for the benefit of the defence sector more broadly. However, an enterprise and multi-national level common approach to this is yet to be agreed upon.

5.3 Technology Solutions

The technology that is used today in the offshore (marine) sectors could potentially provide significant benefits to the Defence sector. In particular in areas of passive monitoring and autonomous field resident systems. The ability to have instruments that can navigate to pre-determined positions on the seabed and observe for an extended period of time, communicate an alert through a network of subsea assets to an autonomous vehicle, which in turn alerts the control station has been demonstrated outside of defence. In addition, seabed monitoring systems are being deployed. Some have been deployed for over 10 years, with secure long range acoustic communications and short range high bandwidth optical communications.

There is considerable Oil & Gas seabed/subsea infrastructure, which if paired with compatible communication and navigation instrumentation, it could be utilised for defence purposes, security accreditation and correct geographical coverage notwithstanding.

Likewise, technology developed for diver detection for maritime security has transferred in to the Oil and Gas sector as an asset integrity monitoring system. Instead of detecting divers the sonar system detects hydrocarbon leaks around wells.

There are a whole host of 'similar' technology programmes in the marine sector, a mere snapshot of some of these are briefly referenced below under key systems of systems themes. If studied further, with collaboration between defence and non-defence sector groups a much larger understanding of the common areas could be catalogued.

5.3.1 Systems Integration: Modelling & Simulation

Collecting real-time information on the underwater environment, in far greater fidelity and higher density coverage zones, is becoming increasingly important for modelling & simulation and also real-time prediction for optimising / calibrating sensors and communications equipment in the field. In Defence this is broadly in-hand however it is worth highlighting the approaches being made outside this sector. Datasets are being made available from a variety of sources; much of this can be accessed publically or via subscription. Current models are the trend however historical models are still of use as when coupled with pattern analysis software techniques can help to find certain parameters of interest. Below are some example tools:

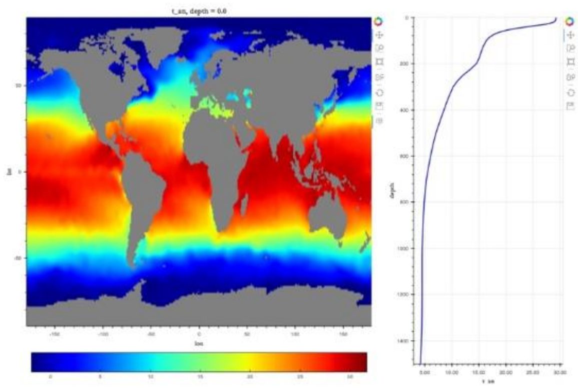

Fig. 1. Open Source Environmental Data Science [1]

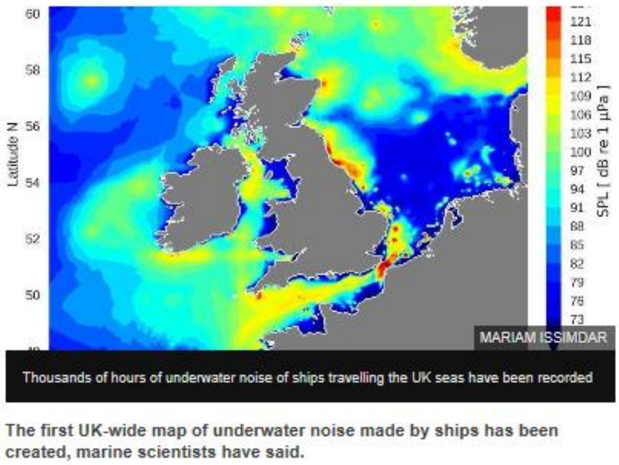

Fig. 2. Ambient Noise Models – BBC / Cefas report [2]

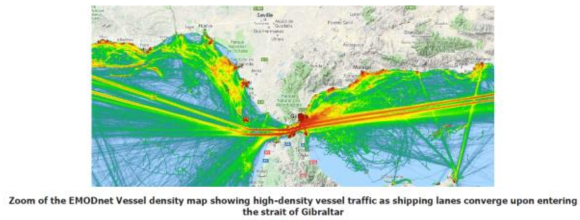

Fig. 3. European Marine Observation and Data Network database [3]

5.3.2 Systems Integration: Test & Evaluation

In addition to Modelling & Simulation, the need to test new technologies 'in the field' and de-risk future programmes for the underwater environment, coupled with the increased use of autonomous platforms and supporting seabed capabilities is driving the need to further invest in at-sea test ranges. Defence is developing its own facilities however, similar facilities are being developed in the marine sector and as such, areas of common transferrable technologies could be de-risked collaboratively using a wider use of Test & Evaluation programmes or facilities.

5.3.3 Sensors & Communications

Consider the Tsunami warning systems that are now positioned at strategic locations throughout the oceans and play a critical role in tsunami forecasting. The Deep ocean Assessment and Reporting of Tsunami (DART) system that was developed PMEL and now operate by the National Data Buoy Centre and the Sonardyne Tsunami system both consist of a subsea tsunami detection system and an acoustic modem that communicate to a moored communication gateway buoy, which is connected via a satellite link to a land based control centre. This infrastructure of over 50 communication gateway buoys could be utilised/learned from for secure defence communication, with messages delayed or even communicated to the seabed system and then relayed to the buoy at a later date. Similarly, autonomous surface vessels are used for harvesting data from seabed recording systems, again these vehicles have acoustic modems and satellite communications, providing a air-water gateway for communications.

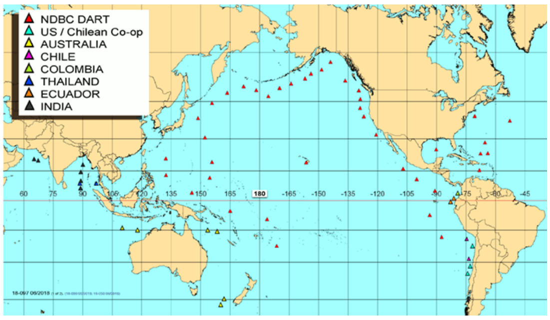

Fig. 4. Map highlighting the locations of the Tsunami detection systems; around predominant fault lines [4]

Other large scale installations could be utilised or learned from such as other surface buoys and seabed nodes.

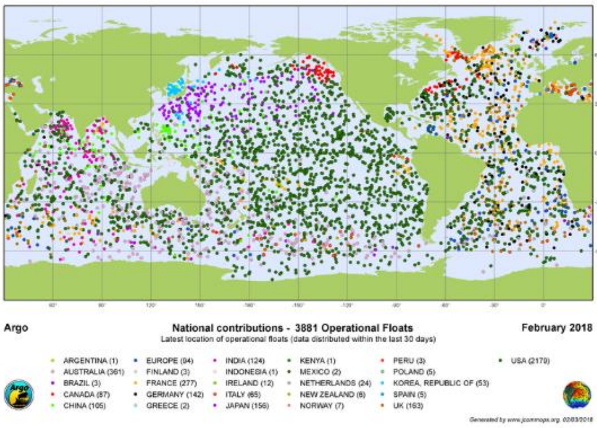

Fig. 5. Map highlighting the locations of the Argo Float network; 3913 Floats across the globe on in April 2019 [5]

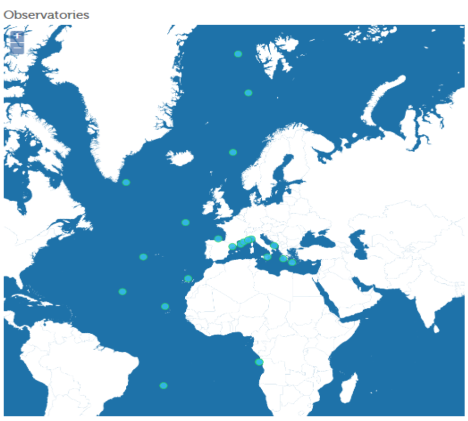

Fig. 6. Map highlighting the locations of one of the many emerging 'Ocean Observatory' networks; this one being the FixO3 programme [6]

5.3.4 *Situational Awareness and C2 – including Positioning and Navigation*

Positioning and the ability to navigate are taken for granted on the surface with the readily available GNSS/GPS service, however spoofing or degradation of these signals has been observed and therefore a robust navigation solution using other references is required. Underwater, there is no GNSS, so typically underwater vehicles or structures are positioned using either a seabed reference system of acoustic transponders, or from a surface ship which has an Ultra Short BaseLine (USBL) acoustic receiver that computes the range and bearing to the vehicle. With the advances in Inertial Navigation Systems (INS), combined with Doppler Velocity Log (DVL), the absolute measurement update is required less frequently. For example, demonstrations of Sonardyne's tightly coupled DVL INS (SPRINTNav) showing only 3m error after 11km, hence less than 0.03% distance travelled. However, INS and DVL systems do still drift over time, so a robust hybrid navigation solution typically requires sparse subsea acoustic reference transponders or periodic position updates from a surface vessel.

To remove the need to deploy reference acoustic transponders, hybrid navigation solutions are using natural and manmade seabed features as absolute references. These can be detected using sonar or optical based imaging systems, which when tightly integrated provide a robust positioning solution. This is often referred to a Simultaneous Localisation and Mapping (SLAM), which is now possible in real-time on-board the Autonomous Vehicle as the image feature search area, orientation and scale is highly constrained or known.

If the positioning solution is of high integrity it is then possible to map or 3D image the seabed infrastructure to provide an accurate dimensional controlled point cloud of installations without contact. Several subsea assets have been imaged using laser line imaging systems, which with a single camera can provide depth information based on where the laser line intersects the camera image. These types of systems, can, with the correct attention to the positioning solution provide milli-metric accuracy 3D images.

UK Government, through Innovate UK, is funding a number of projects in this area. Some of these projects and partner organisations are highlighted below.

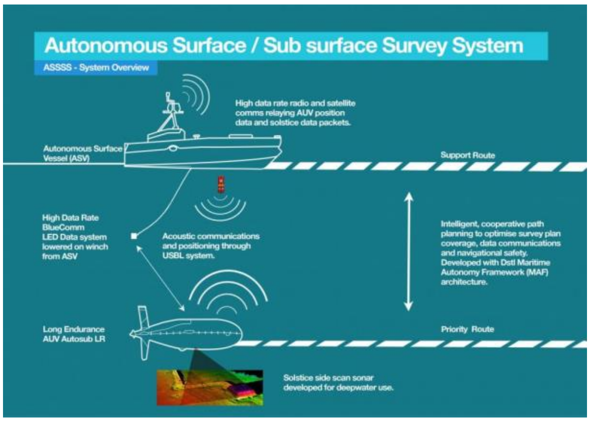

Fig. 7. Diagram of the L3-ASV led collaborative project with Sonardyne, Seebyte and The NOC. In addition, further to this work is a Sonardyne led, again with L3-ASV and The NOC, into the development of Precise Positioning for Persistent AUVs [7]

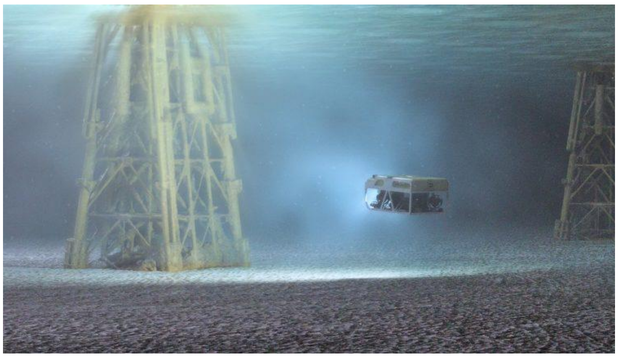

Fig. 8. ROVCO in the UK is applying SLAM with Machine Learning and specialist underwater imaging technology to vastly improve the fidelity of underwater asset inspection and intervention [8]

5.3.5 Platforms & Infrastructure

Typically, in defence, one tends to think of the platform as the large 'capital asset' such as a Submarine or a Ship. Whilst this is true, it is indeed the main asset, there are other platforms that are smaller in scale, and currently limited in their capabilities, but none the less will be reliant upon the 'host' platform be it a mothership or seabed-based. If the use of autonomous off-board systems increases, there is likely also to be an increase in the supporting infrastructure such as docking for 'garaging' or power/data replenishment purposes, often now referred to as 'E-Robotics' or 'Resident Systems'. Such infrastructure may also be integrated as part of an existing seabed platform, thus, the seabed infrastructure may be serving to support the autonomous vehicles, whilst also serving its own purpose as a sensing and communications platform. The following are again a small selection of projects from outside of the defence sector.

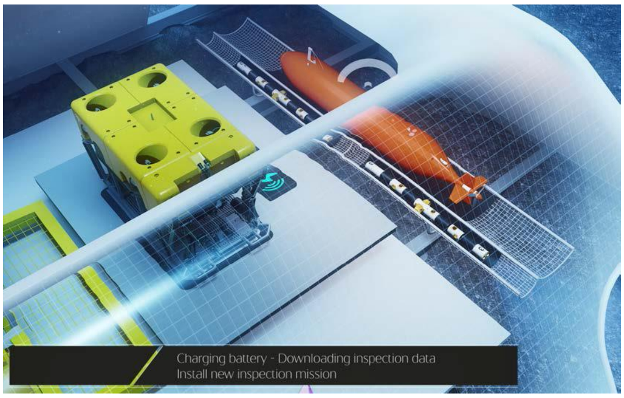

Fig. 9. 'Resident Systems': Underwater Inspection/Intervention Drones and Energy & Docking [9]

Fig. 10. Location of the Snøhvit field in the Barents Sea; could underwater energy infrastructure be a target by hostile actors, or could the infrastructure serve to support future 'Resident Systems' even for Defence? This would pose many questions [10]

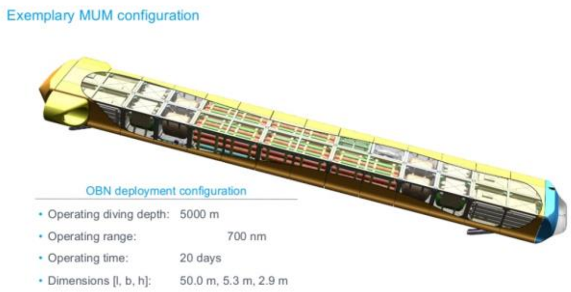

Fig. 11. 'Modifiable Underwater Mothership'. Large and Extra Large UUVs are gaining a lot of interest (and speculation) in Defence, could similar projects outside of defence solvesome of the technology and integration challenges? [11]

Fig. 12. Ocean Infinity's'mothership' and deployable autonomous underwater vehicles – providing the host platform with organic assets, integrated with Launch & Recovery Systems for multiple worldwide missions [10]

6 Conclusions

6.1 Cross Sector Considerations

This paper has examined the similarities between the defence and non-defence sector referred to as marine, herein. There is evidence that supports the argument that deeper examination and considerations should be made towards the more formal collaboration between the sectors. Whether this can be done through design or by inevitable convergence is a matter of choice, however, clearly a more focused campaign to drive cross-sector innovation, transfer of technology and development of skills and shared manufacturing or test & evaluation capabilities can only be achieved if advocated by cross-sector leadership. One area of skills transfer for Defence is pull-through of training and/or people for the operation and maintenance of AUV/ROVs. There is already good representation of the sectors through government backed initiatives and industrial bodies, of which the latter, can provide further analysis and evidence and present this to defence government and industry leaders on potential areas for collaboration; deep-sea and seabed a likely candidate for further investigation. The Society of Underwater Technologies is an example professional body that provide sector representation and working with defence government and industry leaders to conduct further work and coordination. The SUT is a global organisation and in the UK there are a number of other key organisations such as The NOC or more specific Oil & Gas organisations to support this agenda, the same is no doubt true across the Scandinavian region where by there is again a strong defence and marine sector overlap, the same in US and Canada and hence if possible this collaboration, whilst initially being looked through a UK lens, could evolve to a more global coordinated initiative.

6.2 Recommendations

Considerations for further work have been discussed and the following recommendations are suggested for areas of future research, predominantly a UK defence and marine sector set of recommendations:

- Access to global environmental datasets for use within underwater modelling & simulation toolsets – noting a lot of this is becoming more widely open source
- Provision of 'anonymous passive detection' from nascent deployed systems in the marine sector such as through the proliferation of sensors and new underwater infrastructure eg. ocean observatories, argo floats and other similar sensor systems
- In addition to the above sensor data, access to 'old data-sets' for data analytics and improved predictive pattern of life analysis
- Agreement on the protection and responsibilities of critical seabed infrastructure and undersea cables or the techniques to sense and respond to failures, innocent or malicious, physical or electronic
- Collaboratione on common challenges that aren't too 'sector specific' such as: seabed mapping, seabed intervention, energy harvesting, marine bio-fouling, advanced manufacturing and test & evaluation of agreed technology areas
- Underwater communications, navigation and positioning techniques is another area where there will be some similarities in the skills base but not in the specific solutions. Notwithstanding different information security considerations mentioned

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[2] https://www.bbc.co.uk/news/amp/uk-england-suffolk-47375006

[3] http://www.emodnet.eu/sites/emodnet.eu/files/public/secretariat/press%20release_EMODnetVDM_Secretariat_FINAL.pdf

[4] https://nctr.pmel.noaa.gov/Dart/

[5] http://www.argo.ucsd.edu/About_Argo.html

[6] http://www.fixo3.eu/observatory/

[7] https://www.asvglobal.com/asv-global-continue-to-trial-auv-tracking-system-in-loch-ness/ https://www.sonardyne.com/p3auv-collaboration-project/

[8] https://innovateuk.blog.gov.uk/2019/01/04/working-towards-autonomous-underwater-vehicles/?utm_content=82051832&utm_medium=social&utm_source=linkedin&hss_channel=lcp-13185421

[e] Collaboration could be defined in many ways such as joint investment, joint development, manufacturing or simply sharing of data

[9] http://www.subops.no/content/uploads/2018/05/Marianne-Bryhni-Asla-pa-nett.pdf

[10] https://www.researchgate.net/figure/Location-of-the-Snohvit-gas-field-in-the-Barents-Sea-and-the-Hammerfest-LNG-plant_fig1_266260618

[11] https://www.slideshare.net/kaipohlmann/deep-sea-mining-and-advanced-technologies-for-ocean-mining-monitoring

[12] https://oceaninfinity.com/

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Darryl Newborough is the Technical Director at Sonardyne and his career with Sonardyne began in 2002 as a development engineer, after completing his Ph.D at Loughborough University in 2002. During his time with Sonardyne, Darryl has held a variety of senior engineering leadership positions leading up to his appointment as the Technical Director in 2015. Throughout this time, he has been instrumental in maintaining Sonardyne's enviable reputation for innovation and performance, a reputation that now extends far beyond acoustic navigation into inertial, optical and sonar technologies.

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Chartered Engineer and underwater systems and C4I specialist, is a Senior Technologist at BAE Systems Submarines in the UK and consults on technology strategy and research for MoD investment into underwater programmes covering submarine communications and off board systems. As a scientist in government and other appointments as an engineer in industry, he has 15 years working on a wide range of research and development activities for UK, US and European programmes.

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