# Periscope Network

## Market Opportunity Report

Smart Inspection and Maintenance; Underwater Operations

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## Remote and Autonomous Systems Opportunities in the Offshore and Subsea Energy Sector.

### Intervention, Inspection, Survey and Construction support.

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**DATE //** 21 November 2020

In partnership with

## Document History

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## Disclaimer

## Contents

# 1 The introduction of Robotic and Autonomous Solutions in the Offshore Energy Sector

Rapid increases in processing power have enabled the advance of machine learning. When accompanied by evolution and miniaturisation of sensor technologies this provides a strong driver for the growth of Robotic and Autonomous Systems (RAS). Aerospace, automotive, and space sectors currently lead the way with investment in autonomous systems whilst the rapidly growing offshore renewable energy sector provides a prospective new market opportunity.

Technology advances and a common desire to remove the need to put humans out to work in often dangerous and repetitive situations is now driving the study of RAS across every area of business activity. These are as diverse as financial services, insurance, recruitment, fruit picking, defence, nuclear waste handling, marine operations, air freight, Health & Social Care, Oil & Gas and space.[1]

## 1.1 The Global RAS Market

Robotics and Artificial Intelligence have the potential to be globally transformative technologies with the potential to disrupt a range of industries over coming decades. The global market impact of robotics is estimated to be £1.6-£6.4 trillion per annum by 2025.[2]

The ascent of what has been described as the "fourth industrial revolution" provides a clear new business opportunity for both established and emerging companies, with RAS opening up new insights and related value chains in a whole new area of economic activity.

In terms of the global supply of robotics worldwide an International Federation of Robotics (IFR) study highlights the trend from 2000- 2018, shown in Figure 2 below, which highlights very rapid growth over recent years and clear acceleration of demand into the future.

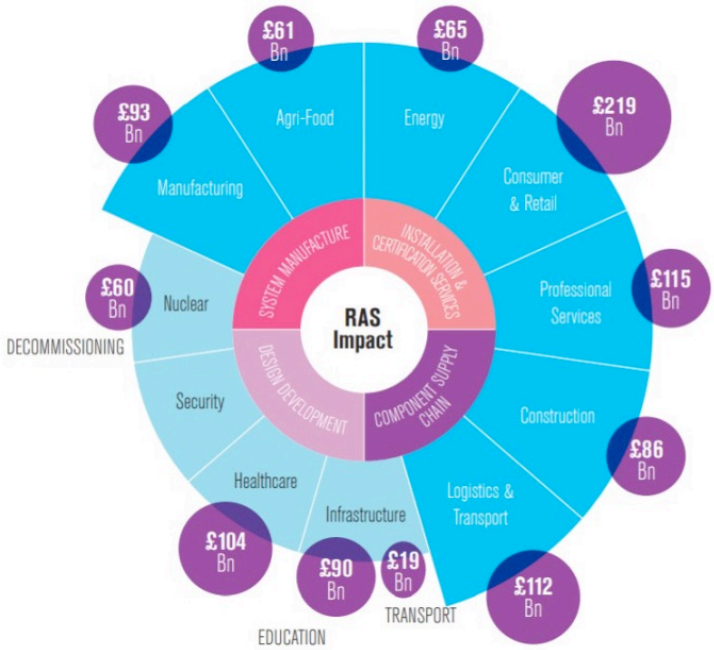

Figure 1 Market sizes affected or disrupted by the introduction of new RAS products and Systems. UK to 2025

[1] Heriot-Watt University and Texo Drone, *2018*
[2] Heriot-Watt University and Texo Drone, *2018*

For a more in-depth review of Global and National investment into the robotics sector and an insight into the World leading robotics companies see paper 'State of the art review into robotics for offshore energy sector.' [3]

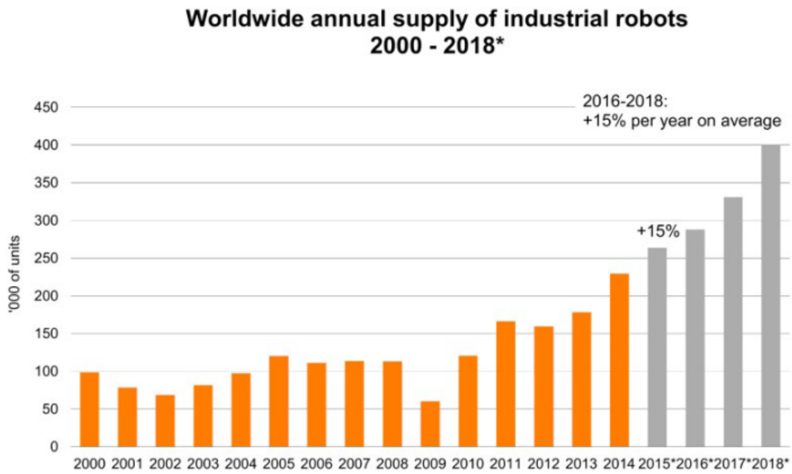

Figure 2 Worldwide annual supply of robotics. IFR World Robotics 2015

### 1.1 The Offshore Renewable Energy Sector and RAS

The Offshore Renewable Energy (ORE) sector can be considered to have been slow to react and consider how autonomous systems could support offshore operations with the sector remaining intensely dependent on human intervention across all project stages from site assessment and installation through to operations & maintenance and decommissioning. The evolving convergence of robotics into key functions within the ORE sector will also likely be undertaken via a progression from semi to full persistent autonomy. This offers the opportunity to revolutionise O&M functions for example, creating new business models throughout the lifecycle of ORE systems.

On the technology side, historically autonomous systems were limited to the experimental use of small surface platforms (gliders) to collect environmental and resource data. However, more recently significant levels of National and Global investment, alongside the potential of evolving new markets, has seen huge growth in autonomous systems and the identification of a wide range of potential tasks that could be carried out by machines. This includes environmental data collection, wind turbine blade inspection, offshore asset inspection, subsea asset inspection, spares provisioning, crew transfer and offshore array security patrol. New considerations such as the global pandemic will also likely drive the need for RAS systems, helping to remove humans from high risk situations and manual interactions.

There is increasing recognition that RAS will have a huge part to play in helping the offshore wind, wave and tidal sectors meet cost reduction, production and productivity targets. This emerging technology area has the potential to create gains in all areas of offshore renewables – from autonomous underwater vehicles that take personnel out of risky

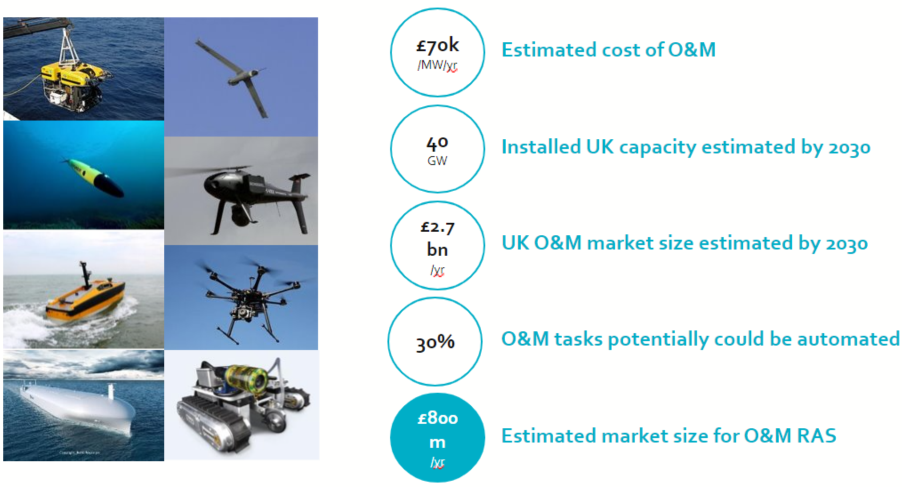

Figure 3 UK market opportunities for RAS in the ORE sector. ORE Catapult, 2020

[3] Heriot-Watt University and Texo Drone, 2018

subsea environments, to advanced drones that can perform rapid blade inspections.

This report will focus on Offshore wind as the predominant market opportunity in the Offshore energy sector, but many requirements and opportunities identified are transferrable to the development of other marine energy technologies as their markets mature.

### 1.1.1 The Global Offshore Wind Market

30 years ago, there was not a single MW of wind installed offshore but with current market predictions there could be up to 1,400 GW installed worldwide over the next 30 years. As we push through 30GW global capacity for offshore wind, exponential growth has been suggested with many nations seeing offshore wind as one of the key strategies to successfully meeting carbon and GHG emissions reduction targets, heading for net zero emissions standards and some semblance of control over global warming.[4]

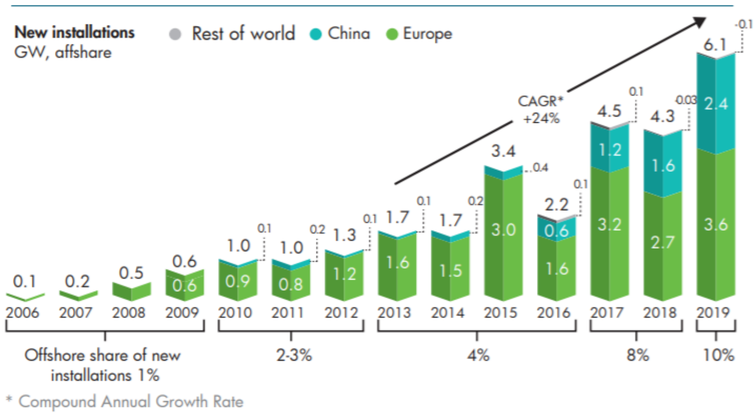


Figure 4 GWEC Market Intelligence, 2020

2019 was a record year for offshore wind with 6.1 GW of new capacity added. China also achieved a new record installing 2.4 GW offshore wind in a single year. The United Kingdom came in second place, although it also had record installations of 1.8 GW in 2019. With 1.1 GW of new installations, Germany took the third place, followed by Denmark and Belgium. With an average annual growth rate of 18.6 percent until 2024 and 8.2 per cent up to the end of the decade, new annual installations are expected to sail past the milestones of 20 GW in 2025 and 30 GW in 2030.[5]

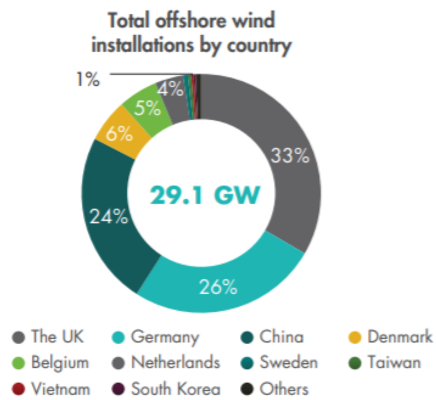


Figure 5 Total Offshore WInd Installations by Country. GWEC Market Intelligence 2020

As the world's largest regional offshore wind market, Europe is expected to maintain steady growth, but new installations outside Europe, predominantly from Asia and North America, are likely to surpass Europe in 2020 for the first time and continue exceeding volume in Europe through 2030. In the near-term (2020-2024), the majority of growth outside of Europe will primarily come from China and Taiwan, with the contribution from the US becoming sizeable from 2024 when the first utility-scale offshore project comes online.

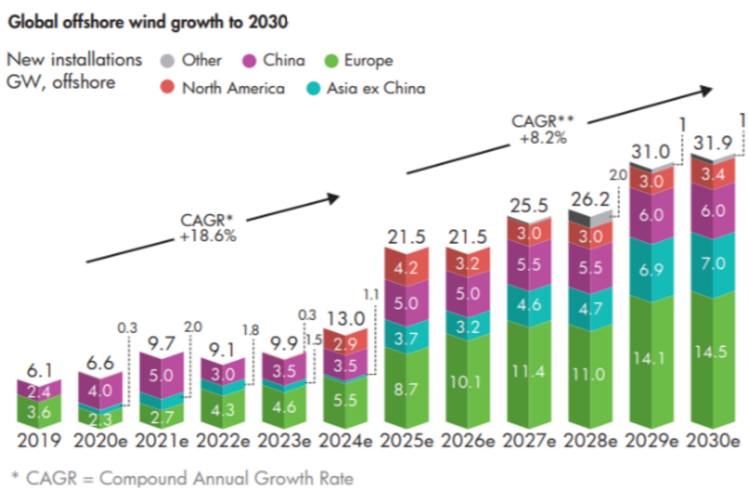


Figure 6 Global Offshore wind growth to 2030. GWEC Market Intelligence 2020

For further analysis and insights of global offshore wind markets see Global Wind Energy Council, Global Offshore Wind Report 2020.[6]

[4] Global Wind Energy Council, Global Offshore Wind Report 2020
[5] Global Wind Energy Council, Global Offshore Wind Report 2020
[6] Global Wind Energy Council, Global Offshore Wind Report 2020

### 1.1.2 The emerging Floating Offshore Wind Market

In very recent years we have also seen the strong emergence of a new Floating Offshore Wind (FLOW) sector. FLOW offers an opportunity to exploit the offshore wind resource available in water depths that cannot be accessed by Fixed offshore wind. Key markets have been identified in Europe, the USA and Japan with the potential for 7,000GW (GlobalData 2020[7]) to be deployed globally, generating approximately 30,000TWh/yr which is well in excess of current global electricity demand (23,105 TWh in 2019 - Enerdata.net 2020[8]). By 2019 there was 11.4 MW of floating wind installed, of which 8.4 MW is from Portugal and 3 MW from Japan. A total of 65.7 MW floating wind is planned in 2019, of which 32 MW is located in the UK, 19 MW in Japan, 10.4 MW in Portugal, 2.3MW in Norway and 2 MW in France.

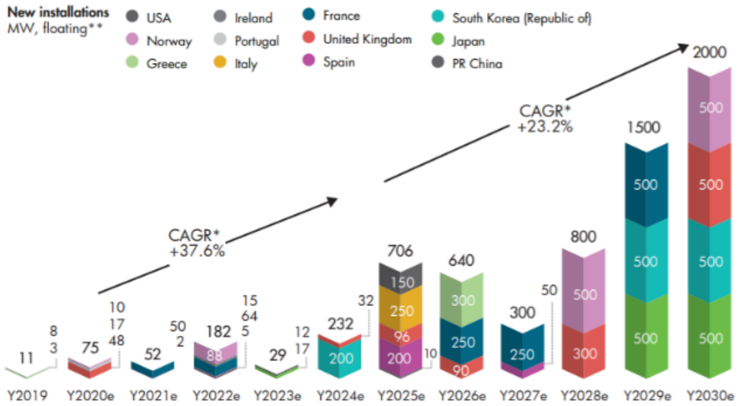


Figure 7 FLOW forecasted deployment. GWEC Market Intelligence 2020.

At present, the 2030 FLOW forecast ranges from 3 GW to nearly 19 GW, depending on how quickly LCOE can be brought down to an affordable level and its adoption by new markets. GWEC Market Intelligence predicts 6.2 GW of floating wind is likely to be built in the next 10 years.

We have also seen the recent adoption of specific FLOW policies and targets. In 2019 The UK Government, for example, set an ambitious target to deliver 40GW of Offshore Wind by 2030 with 10GW coming from FLOW in an effort to reduce greenhouse gas emissions to zero by 2050 whilst offering specific manifesto support to 'enable new floating wind farms'.

## 2 Areas of potential intervention in the Offshore Energy Market

Now we have established prospective markets and their future value in the Offshore energy sector, this section of the report will specifically focus on the potential opportunities and interventions in the sector for RAS. Many of the hardware systems required for more advanced and autonomous operations are commonly available on the market with current sector developments having a strong focus on system integration and data analysis from these technologies.

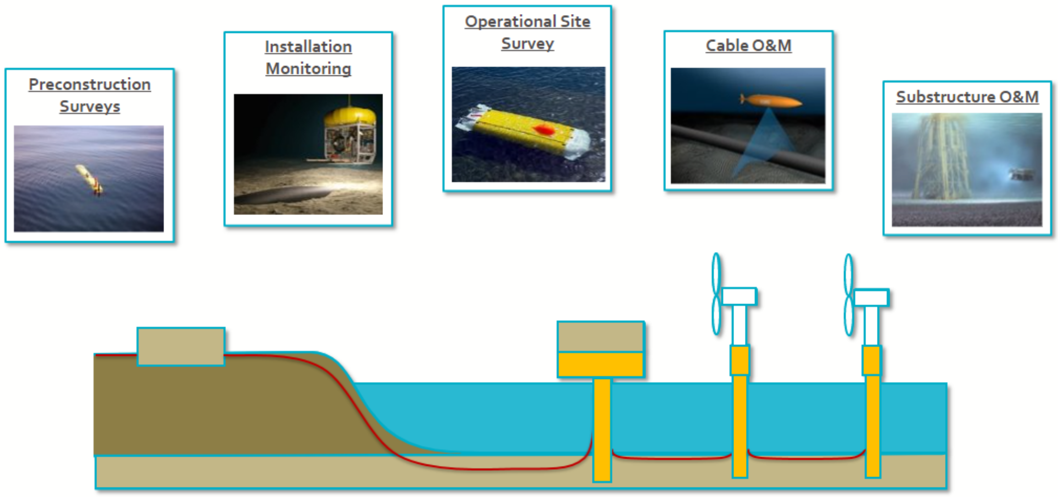


Figure 8 RAS ORE Intervention areas. ORE Catapult

[7] https://www.energylivenews.com/2020/03/12/floating-wind-potential-across-europe-the-us-and-japan-is-as-high-as-7000gw/
[8] https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html

## 2.1 Site Surveys

Figure 9 BlueFin Robotics ASV

Site surveying offers a clear opportunity for RAS integration and innovation with applications across a range of sectors including ORE.

In relation to the current state-of-the-art, robot technologies have been used for geotechnical and bathymetry surveys for over 40 years. AUVs, gliders and ASVs have different strengths and weaknesses for their use as host vehicles for sampling and mapping the Ocean environment, with variable launch and recovery options, endurance capabilities and payload capacities.

Appendix 1 provides a summary of the range of AUVs and ASVs available on the market today as well as their potential suitability for various subsea applications. The identification of the potential global offshore wind market discussed in previous sections provides a clear indication of the future market opportunity in this specific sector alone. To provide an indication of the spatial capacity of this market, ongoing development around FLOW in the Celtic Sea, UK, alone is initially focused on an area of sea 25,000$km^2$ in extent that will require significant surveying and data collection capabilities.

## 2.2 Offshore Logistics

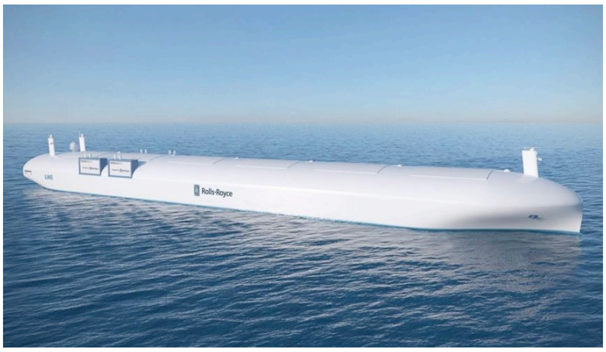

Figure 10 Rolls-Royce illustration of an autonomous maritime vessel

Offshore logistics has relevance to both the ORE sector and wider sector requirements. A ship's ability to monitor its own health, establish and communicate what is around it and make decisions based on that information is vital to the development of autonomous operations, with the primary technical requirements of autonomous maritime logistics, relating to Sensor Fusion, Control algorithms, and Communication and connectivity. Ongoing challenges exist in this sector around reliability and the most efficient integration of enabling technologies such as thermal imaging and Lidar as well as accompanying control algorithms.[9]

The Rolls-Royce, Advanced Autonomous Waterborne Applications initiative (AAWA), represents one of the most significant investments in the sector to date. Market opportunities are extensive with a key opportunity to affect both cost and emissions levels of the maritime transport sector, a significant contributor to global emission levels.[10]

[9] Heriot-Watt University and Texo Drone, 2018

[10] Maritime transport emits around 940 million tonnes of $CO_2$ annually and is responsible for about 2.5% of global greenhouse gas (GHG) emissions (3rd IMO GHG study).

## 2.3 Construction & Infrastructure inspection

The construction and infrastructure inspection sector has seen the early adoption of RAS solutions with visions of a building site of the future swapping men, hard hats and high vis jackets for drones overhead, robotic bulldozers and 3D printers on site and in assembly lines manufacturing structural components.

| COMPANY OR INSTITUTE | ROBOT | APPLICATION |
|---|---|---|
| Spectra Drone Services, LLC. | Spectra | Aerial inspection |
| Fraunhofer Building Innovation Alliance | Betoscan | Concrete floors |
| Iris Power | RIV800 | Generators |
| GE | Bike | Ferromagnetic Structures |
| ROVCO Subsea | Sub-Atlantic Mojave | Subsea Assets |
| USACERL and RedZone. Robotics, Inc | Pioneer P3-AT | Roads |
| MIT | Mag-Foot | Bridges |
| University of Catania | SURFY | Storage Tanks |
| University of Virginia | Polecat | Light Poles |

Figure 11 A selection of different robotic systems for infrastructure inspection. Heriot-Watt University and Texo Drone, 2018

Again this market has direct relevance to the ORE sector with both onshore and offshore construction and infrastructure requirements and well as wider construction sector developments.

## 2.4 Blade, Nacelle and Tower Inspection in Offshore Wind

The inspection of wind turbines and their components requires a number of capabilities and functions that can be delivered by RAS. This provides the opportunity to maximise efficient wind turbine operation, minimise turbine downtime, reduce operational emissions and remove the requirement for manual intervention in hazardous offshore environments.

| NAME | COMPANY OR INSTITUTE | TYPE |
|---|---|---|
| RIWEA | Fraunhofer IFF | Wire-driven |
| Maintenance robot | Korea Institute of Science and Technology | Wire-driven |
| DashWin | DashWin | Wire-driven |
| Telerobot Prototype | Norweigian University of Science and Technology | Rail-guided |
| HR-MP20 | Helical Robotics | Climbing (Magnetic adhesion) |
| ICM Climber | International Climbing Machines | Climbing (Vacuum adhesion) |
| OmniClimber | University of Coimbra, Portugal | Climbing (Magnetic adhesion) |
| Micro Aerial Vehicle | KAIST, Daejeon, Korea | Flying and Climbing |
| AscTec Pelican | Ascending Technologies | Flying |
| Aibot 6 | Aibotix | Flying |

Figure 12 A list of different robotic systems developed for wind turbine inspections. Heriot-Watt University and Texo Drone, 2018

RAS options in this intervention area can be split into three main groups; climbing robots, wire-driven robots and flying robots. Figure 12 provides a list of some of the systems available on the market today. Each system provides a range of benefits and functions, for example flying robots can access areas that can't be reached by climbing robots but this comes with a reduction on payload capacity and operating time. Table 1 below expands on these attributes and functions to help demonstrate key intervention areas for each system type. To enable the full inspection requirements to be for offshore wind turbines a number of system types may be needed, ideally operating within a synchronised managements and control system.

Table 1 Example System type, function and attributes

| Type | Target function | Main attributes | Example | Prospective payload | Image |
|---|---|---|---|---|---|
| Wire Driven Robots | WT blade inspection. Detection of near-surface air inclusions or de-laminations and deeper de-laminations or problems with adhesive bonds. Blade defects. | Wire-driven robots typically use wires or ropes attached to the outside of the WT structure in conjunction with motors to allow them to move to areas for inspection. | The RIWEA system [11] | Active thermography, ultrasound + high-resolution camera systems. |  |
| Climbing Robots | WT inspection. Can include NDT and 2D/3D imagery. | Magnetic / Vacuum suction to enable adhesion to WT surfaces. Highly manoeuvrable | HR-MP20. Helical Robotics. | Sensing devices including video cameras and specialist equipment. Max. payload of 9 kg, speed of 43.6 ft/minute |  |
| Aerial Inspection | Visual inspection of infrastructure (internal & external). Thermography & hyperspectral investigations. Corrosion inspections are 20x faster than traditional access and measurement methods. Potential long-range surveys. | Several possible designs, including rotary helicopter, fixed-winged systems or quadcopter drones. | Texo DSI | UAV-integrated, survey-grade LiDAR system (1-3mm in cloud accuracy). High def video. |  |

[11] Robot for the Inspection of Wind Turbine Rotor Blades

### 2.4.1 Benefits and requirements for RAS in Inspection and Maintenance for offshore wind

Figure 13 ICM crawler

Significant research and investment has been committed to the evolution of RAS systems in this intervention area driven by the risk posed to human life, the cost and the inefficiency of manual WT inspections and the progressively expanding capabilities of RAS solutions. As has been mentioned the functions and capabilities required for inspection and maintenance will likely require a mixture of RAS platforms, including Unmanned Aerial Vehicles (UAVs), crawlers, Autonomous Surface Vehicles (ASVs) and Autonomous Underwater Vehicles (AUVs).

We have previously discussed the extent of the prospective offshore wind energy market in the preceding sections of this report and it is useful to now relate this prospective market to the quantifiable number of RAS systems that could be involved in the inspection of current and proposed offshore wind energy developments. Figure 14 provides an estimate of the number of robots that might be deployed in remote inspection of various wind farms, mapped to the baseline assumptions of 3 robots per turbine, 30 for each internal substation, 5 per external substation inspection and 5 for subsea inspections (cable/ infrastructure) per 100 km2. [12]

| | Turbine | Ext. Insp. | Int. Insp. | Subsea | Total |
|---|---|---|---|---|---|
| London Array [ii] | 525 | 10 | 60 | 5 | 600 |
| All UK Farms [iii] | 4700 | 200 | 1200 | 2000 | 8100 |
| Dogger Bank [iv] | 2400 | 100 | 600 | 120 | 3220 |

Figure 14 Inspection robot number estimates. Homeoffshore.

It is however very important to note that an assumption in this analysis is that the cost of deploying robotic platforms is less than existing manual-based methods or the use of fixed-point condition monitoring. This case remains to be fully justified and is a feature of future PERSICOPE activity highlighted in the later recommendations section of this report.

RAS systems are already actively delivering clear benefits to this sector. Time consuming manual access solutions are obviated by UAV inspections, which can remove the need for plant shutdowns and allow assets to be inspected while they are live. Time and cost savings are achieved as well as numerous operational and safety benefits. Many of today's RAS systems involve the use of multiple UAV platforms with dual payloads and cameras/sensors that use a variety of high-quality, factor calibrated and interchangeable lenses that are tailored to meet varying requirements. Visual and thermal analysis can be carried out simultaneously in one inspection or survey, covering everything from coupled structural thermal analysis to hot spot identification (to identify potential failures in the wind turbine gearbox), leak detection and water ingress detection (within the wind turbine tower). Advanced flight control and the latest software systems allow for highly detailed orthomosaics to be stitched together seamlessly; this gives a complete and highly detailed overview of the specified target area.[13]

Investment is driving ever greater accuracy across all RAS operations, with LiDAR surveys a great example. UAV survey and inspection technology offer huge advantages in every part of the offshore wind asset life-cycle – from

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[12] www.homeoffshore.org.uk

[13] Heriot-Watt University and Texo Drone, 2018

site planning to operations and maintenance. Traditional ground (boat)-based surveys typically take ten times longer to carry out than a LiDAR survey.[14]

### 2.5 Subsea Inspection

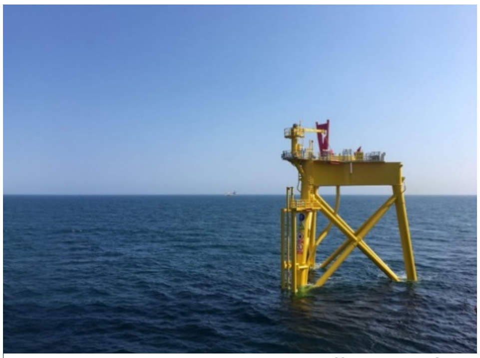

Figure 15 An Offshore platform

The examples of RAS utilized in the previous section focus on above sea solutions but RAS has an equally important contribution to make in sub-sea interventions. Indeed, one of the critical challenges recognized within the ORE industry is the capability for efficient, safe and costs effective subsea surveys of cables, foundations and the surrounding sea-bed.

Subsea inspections are vital to offshore wind, wave and tidal project developers – but they're also expensive, time-consuming, and labour intensive to carry out, creating an opportunity for developers of RAS that can increase reliability and confidence while cutting costs and time. Data also helps developers and owner/operators make smarter operations and maintenance decisions, improving efficiency and lowering costs.

#### 2.5.1 Foundations

There are several aspects of the foundation that are of interest in terms of inspection. These include the Internal corrosion of monopile foundations, scour, including local scour around foundations and cables, Global scour in the wind farm, Subsea weld integrity and fatigue crack growth. All of these functions are, or have the potential to be carried out by underwater vehicles.

It is important to note that not all turbines in a wind farm will be simultaneously surveyed. Wind farms are typically divided into quadrants. One quadrant will undergo a survey every 6 months – cable corridors and seabed survey. A Small subset of the turbines will be selected for detailed inspection including scour. Foundation designers recommend each turbine gets a scour inspection every 5 years

Figure 16 Fixed Offshore wind turbine foundation

#### 2.5.2 Offshore substation Maintenance.

Figure 17 Hydrasan AUV

RAS within substations offshore, both subsea and out of water, require teleoperated or semiautonomous capabilities whilst minimising operational risks to the asset. The primary challenges in this environment relate to long term operation in electromagnetically harsh areas, accurate localisation in the dark, GPS denied environment and clear fault detection and verification to supplement the existing systems.

[14] Heriot-Watt University and Texo Drone, 2018

### 2.5.3 Export and inter array cables

Offshore installations rely on various infrastructure assets such as subsea cables that export the power to shore and internally within the wind farm through inter array cables. Reliability determines the sustainability of power supply and economic viability alongside risk profiles.

To demonstrate the importance of this critical infrastructure; for a 300-MW wind farm, loss of revenue from a power outage due to a fault in one of the subsea cables is approximately £5.4 million per month[15], and the cost for locating and replacing a section of damaged subsea cable £0.6 million to £1.2 million[16]. It can take months to repair a subsea cable, with failures directly affecting large revenues streams, while any delay in repair and replacement can cost more than €20,000 per extra hour[17]. 75%-80% of the total cost of insurance claims related to offshore wind farms are associated with cable failures while the total cable expenditure only accounts for around 7%-9% of the capital costs for a new wind farm[18].

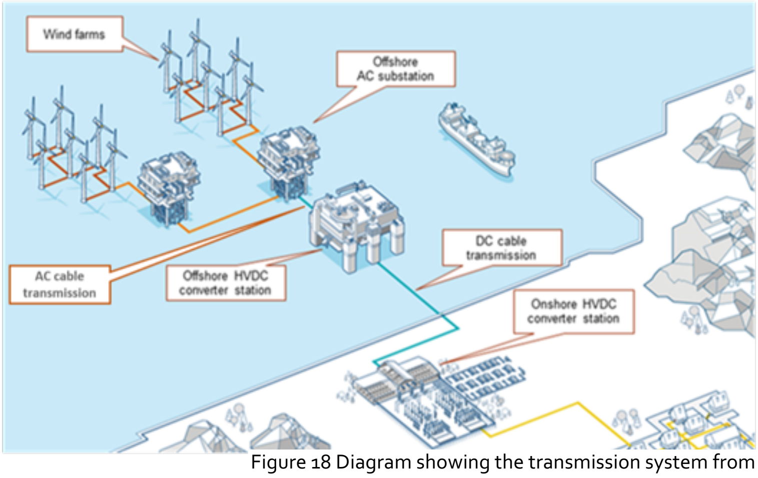

Figure 18 Diagram showing the transmission system from wind farms to landfall point via various cables, substations and converter stations. (Source: ABB)

This known area of significant risk provides a key target area for evolving RAS solutions. At present there is no means of evaluating the 70% of failure modes associated with abrasion, corrosion and third-party impacts. AUVs with magnetometers and wideband low frequency sonar capabilities are being developed to provide unprecedented insight into subsea cable integrity and interactions with the local environment.

Companies including Hydrason are exploring the role of LF Sonar technology as part of a multi-sensor payload on AUVs for site surveys and asset integrity management. Future advances in manipulation capabilities would also be advantageous to support in-situ remedial actions to repair cables without necessitating surface recovery for Iron-collar repair or replacement.

## 2.6 Conclusions and key trends

The long-term industry vision within ORE is for a completely autonomous offshore energy field, operated, inspected and maintained from the shore. At the same time, significant research progress is being made in robotic autonomy, mobility, manipulation, sensor processing, autonomous mapping, navigation, multimodal interfaces and human-machine collaboration.[19]

We are seeing a significant increase in offshore wind turbine size and scale, exacerbating issue of access and safety, whilst increasing turbine capacities multiply the effects of down time on lost revenue for example. In 2012 the

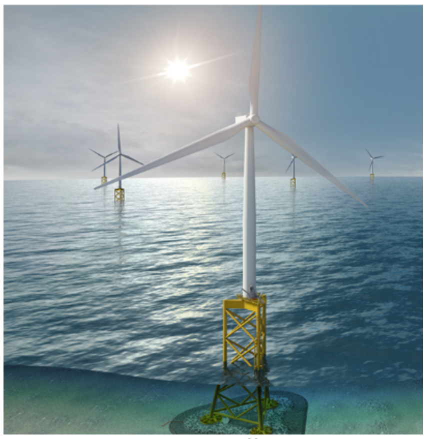
Figure 19 Fixed offshore wind turbine and foundation

[15] "An Insurance Buyer's Guide to Subsea Cabling Incidents", Report by GCube underwriters, http://www.gcube-insurance.com/press/offshorecable-claims-severity-increases-by-25-in-2015/
[16] J. Beale, "Transmission cable protection and stabilisation for the wave and tidal energy industries", 9th European wave and tidal energy conference (EWTEC), 2011, Sep 2011, University of Southampton, UK
[17] Report for the Department for Business Energy and Industrial Strategy (BEIS), Lessons Learnt from MeyGen Phase 1a Part 1/3: Design Phase, May 2017.
[18] Global Marine Energy
[19] Heriot-Watt University and Texo Drone, *2018*

average offshore turbine size was 3.2MW, we are now looking at 15-20MW turbines for introduction in 2025-2030.

Life extension is also now becoming a key consideration as deployed assets age. Understanding foundation health, for example, is critical to this consideration and promotes a need to reduce more costly and higher-risk interventions.

Technology and systems advances in the RAS sector coupled with clear and rapid growth in the offshore energy sector provide a clear opportunity for significant new blue economic growth.

# 3 Current state of the RAS sector: Projects

In order to provide an overview of current activity in the sector, the following section provides a snapshot of some of the related Offshore and sub-sea activities and projects across the UK, Europe and beyond. This provides a clear indication of the prospective technologies that are active or close to full development and their capabilities as well as critical challenges the sector is already seeking to address. It also highlights clear market entry points in specific relation to the Offshore Energy Sector as well as providing an indication of the benefits RAS can bring to the sector and wider ambitions for Greenhouse gas reduction and net zero emissions targets. This is not intended to be an exhaustive project list. The CORDIS database (https://cordis.europa.eu/) provides a further useful reference point to access a wider database of European funded schemes.

## 3.1 Nippon Foundation GEBCO – Seabed 2030 Project

The Seabed 2030 Project, is looking to coordinate and track new survey efforts that will facilitate the development of new and innovative technologies that can increase the efficiency of sea-floor mapping. The Project aims to establish an infrastructure to facilitate the complete mapping of the world ocean floor by 2030, with the view of empowering the world to make policy decisions, use the ocean sustainably, and undertake scientific research based on detailed bathymetric information of the Earth's seabed.

## 3.2 The AVISIoN project

Figure 20 Modus and Osbit. AUV and docking station

The Autonomous Vehicle for the Inspection of offshore wind farm Subsea INfrastructure (AVISIoN) project is a partnership between ORE Catapult, Darlington-based [Modus Seabed Intervention](#) and [Osbit Ltd](#), to design a novel docking station for an Automated Underwater Vehicle (AUV) to enable it to remain at offshore wind farm sites without a support vessel. The docking station will enable vehicle re-charging, as well as the upload of acquired data and download of mission commands. https://ore.catapult.org.uk/stories/avision/

### 3.2.1 Ambitions:

Reducing expenditure - The use of AUVs to survey and inspect offshore wind farm subsea infrastructure is a relatively new cost-efficiency measure in this sector. Replacing support vessels with the AUV docking station could further reduce expenditure.

Increasing safety - The scheme will also significantly reduce the need for staff to work in hazardous marine environments.

### 3.2.2 Requirements:

Testing - AVISIoN has received funding from Innovate UK, which will enable further development, testing and demonstrations of Modus' existing Hybrid AUV capability, and docking station. Testing will take place at ORE Catapult's National Renewable Energy Centre in Blyth. The first phase will use saltwater testing docks and Catapult's National Anemometry Hub. Offshore wind farm developers innogy, EDF Energy and E.ON are also supporting the project, with innogy agreeing to carry commercial trials at the Gwynt y Môr offshore wind farm.

### 3.2.3 Impact:

The use of AUVs could shave £1.1billion from the cost of operating Europe's offshore wind farm fleet in what would be a world-first for the sector. [20]

## 3.3 MIMRee - Multi-Platform Inspection, Maintenance and Repair in Extreme Environments

Inspecting the blades of an offshore wind turbine can be a difficult task. Restrictive weather windows and extreme conditions at sea combine to create a challenging working environment, while lost revenue from turbine downtime and the cost of vessels and technicians make increasing the efficiency of inspections a top priority for the industry.

Figure 21 Thales' Halcyon autonomous surface vessel.

The £4.2m Multi-Platform Inspection, Maintenance and Repair in Extreme Environments (MIMRee) project is an ambitious cross-sector programme combining expertise in robotics, artificial intelligence, marine and aerial engineering, nanobiotechnology and space mission planning to prove that offshore wind maintenance missions can be conducted by unmanned robots.

Funded by Innovate UK, the programme seeks to demonstrate the world's first fully-autonomous offshore wind inspection solution. Eight industry partners, led by non-destructive testing experts Plant Integrity, will work together on this game-changing project that builds on existing innovations.

The Catapult will provide invaluable industry insight, engineering expertise, and world-leading representative testing and validation facilities to prove the MIMRee technologies.

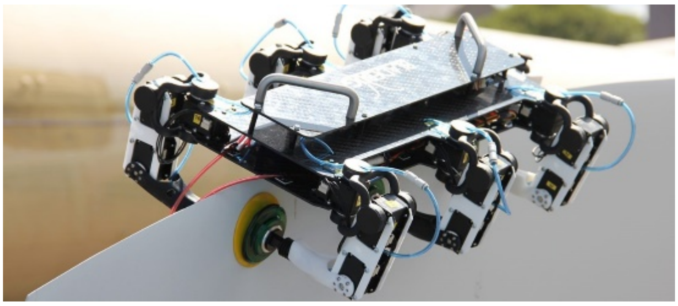

Figure 22 Blade Bug. Wind turbine blade repairs

The Halcyon autonomous vessel developed by global technology leaders Thales will play a key role, as will a drone system under development by the University of Bristol and the crawling robot BladeBUG fitted with a robotic repair arm by the Royal College of Art's Robotics Laboratory. An electronic skin, developed by high-tech start-up Wootzano, will 'feel' the surface and collect a deeper level of data on the blade surface structure. The University of Manchester will develop a system for transporting, deploying and retrieving the blade crawler, while Royal Holloway University of

[20] ORE Catapult. Avision project.

London will lead creation of the human-machine interface that will allow personnel located onshore to analyse the data transmitted by MIMRee and intervene as necessary.

The project's core challenge will be to unite these systems into a holistic solution capable of planning, communicating, sharing data, and working together on complex sequences of tasks.

If successful, future offshore wind farm inspections and repairs will look very different from those of today. Autonomous vessels will be initiating and planning missions, before mapping and scanning wind turbine blades upon approach to understand where the robots should be deployed.

Drones will be launched from an autonomous mothership to conduct visual inspection of the blades and transport crawling robots onto the turbine to conduct hyper-spectral imaging inspection and repairs. An electronic skin, developed by the high-tech start-up Wootzano, will "feel" the blade surface and ensure that the crawler is securely attached while moving on the blade.

Health and safety benefits aside, the project is expected to save the average wind farm approximately £26m over the course of its lifetime. And with applications in offshore oil and gas and defence, it also has the potential to position the UK as a world leader in robotics and autonomous systems development.

Bringing together cross-sector partners to develop never-before-seen technology, this is a project that has the potential to shape the future of offshore wind and push the boundaries of robotic intelligence.

### 3.4 WASP – Windfarm Autonomous Ship Project

The **W**indfarm **A**utonomous **S**hip **P**roject (WASP) is a feasibility study to understand market demand for autonomous vessels offshore and develop scenarios and a concept design of an integrated autonomous vessel delivery system for offshore wind farm maintenance. WASP addresses the identified need, challenge and market opportunity by researching and designing the world's first integrated autonomous vessels and robotic cargo transfer mechanism for delivery of equipment to offshore wind farms.

The project has benchmarked challenges for unmanned surface vessels (USVs) in arrays, characterised USV performance potential and created a sector route map for USV integration into manned vessel operations.

ORE Catapult's cost and performance analysis[21] has pinpointed one of the ways this new capability of USVs can increase uptime of offshore wind turbines. Research conducted throughout the WASP project by the Catapult has identified the benefits of integrating USVs into offshore operations and maintenance in terms of additional revenue, higher productivity and reduced operating costs.

As a result of integrating USVs into offshore operations, this would mean for a 2GW cluster site:

- An upfront capital cost reduction of £7.5m
- An annual operating cost reduction of £850,000, or £21m over a 25-year operating life
- Effective increase in net capacity factor of 0.1% due to faster servicing
- The cost of the USV could be as high as £5,300 a day and still breakeven on the lifetime cost of the site

[21] www.ore.catapult.org.uk/stories/wasp

- Increasing the use of autonomous vessels will also lead to the creation of highly skilled, cross sector jobs in areas such as the integration, planning and supervision of autonomous vessels, boosting the UK's maritime and digital supply chains.

- Also see a strategic roadmap for the introduction of autonomous vessels into manned vessel operations in the offshore wind sector (awaiting final version).

### 3.5 Fraunhofer – Ocean Technology Campus - Subsea technologies

Fraunhofer institutes have bundled their know-how to be able to develop innovative technologies such as subsea vehicles, monitoring stations for aquaculture facilities or detection systems for explosives. The core of the Subsea Navigator (Fraunhofer subsea community) are the basic technologies energy, subsea vehicles, manipulators, sensors, materials and communication.

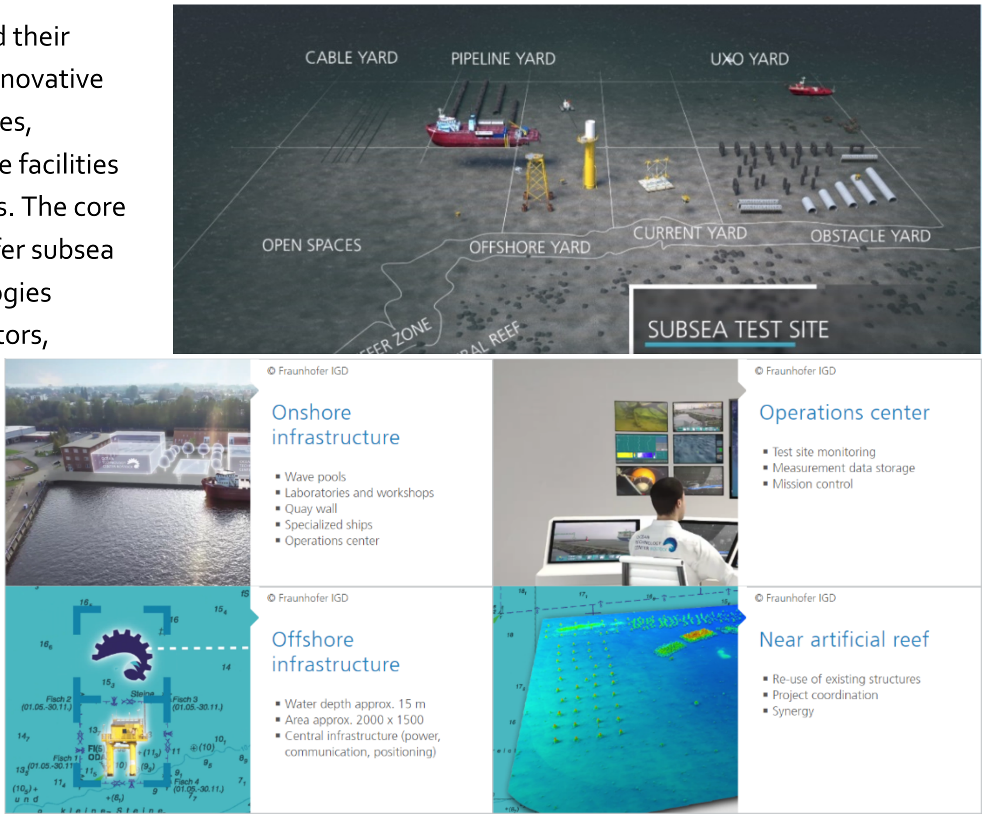

Figure 23 Fraunhofer Ocean Technology Campus

The large-scale project "Ocean Technology Campus" (OTC) will turn the Hanseatic city of Rostock, Germany into a leading location for technological underwater research with a versatile testing area off the coast. At the core of the project is the "Digital Ocean Lab"--an undersea site for testing ideas and simulations under controlled conditions in a real-world environment. On land, the OTC will maintain a bridgehead where researchers from the various project partners will work together. https://www.fraunhofer.de/en/research/range-of-services/research-and-development/subsea.html

### 3.6 CleanWinTur

As existing offshore wind turbines age and new OWTs are situated in deeper waters and further from the shore, maintenance costs become increasingly important in determining OWT lifetime and achieving levelised cost of energy (LCoE) targets set by the government. In particular, dealing with biofouling and corrosion in OWTs' substructure and splash area through traditional means (i.e. divers, coatings, and ROVs) becomes increasingly challenging, costly, dangerous and ineffective. CleanWinTur will address both issues by developing an ultrasonic system that performs continuous condition monitoring and effective anti-fouling thereby enabling the implementation of predictive and/or condition-based maintenance and reduce maintenance costs by 50%. As a result CleanWinTur will help reducing OpEx by 30% while enabling CapEx reductions by allowing less conservative substructure designs. CleanWinTur has therefore the potential of saving the industry millions while generating £38,7M in profits for the consortium and creating 387 jobs 5 years after commercialisation. The project is backed by a prestigious consortium including NDT Consultants, the European Marine Energy Centre, 3-Sci, InnotecUK, Alpha Electro Technology and Brunel University London. https://www.brunel.ac.uk/research/Projects/CleanWinTur

### 3.7 RobFMS

An autonomous, robotic and AI enabled biofouling monitoring, cleaning and management system for offshore wind turbine monopile foundations.

Seabed turbine foundations (largely monopile structures) O&M accounts for at least than 25% of all life cycle O&M costs, mostly caused by marine biofouling amounts to 10% of the LCOE and are incurred through the use of divers, ROVs, a support vessel and substantial human team. Even with the deployment of state of the art fouling prevention technology, the fouling thickness deposited on foundations grows continuously, eventually causing stress induced corrosion and crack defects.

The project vision is to replace this expensive and hazardous technology with an intelligent fouling monitoring and cleaning management system (RobFMS) implemented by an autonomous working team of at two or more small mobile robots operating with AI enabled cost minimisation.

The system would save more than £15kpa/MW (50%) of existing monopile fouling management costs, which is a significant contribution to realising the full environmental advantages of offshore wind. It is also adaptable to other types of offshore turbine foundation.

# 4 Current state of the RAS sector: Business snapshot

Alongside providing an overview of current project activity in the RAS sphere, the following section will provide a snapshot of some interesting business activity across the sector looking at specific technology capabilities and systems development.

### 4.1 MARYNSOL

Edinburgh-based MarynSol specialises in advanced data acquisition, management and analytics solutions. "Our approach is to use marine autonomous vehicles as a survey platform," (J.Evans, MarynSol) "delivering data that answers operations and maintenance questions, efficiently and safely."

#### 4.1.2 SeaSmart

The company has developed SeaSmart, a sophisticated software package that automates the acquisition, processing and reporting of marine survey data and can work across a variety of autonomous vehicle platforms. Using autonomous vehicles can significantly reduce the time and costs associated with the survey mobilisation and operations. These vehicles can operate safely close to the field assets, reducing personnel risks. Surveys can be performed simultaneously with other in-field activities, ensuring the best use of vessels and crews.

However, accessing real-world operational sites for the testing and demonstration of new technologies can be a real barrier to SMEs. MarynSol tested its SeaSmart automated marine survey payload at the ORE Catapult Levenmouth Demonstration Turbine in late October 2018. Performing a successful survey of the seabed surrounding the turbine and its jacket piles, it identified potential hazards in and around the turbine and bay. It also demonstrated that its autonomous method can survey a substantial area in significantly less time than traditional methods while producing reliable, useful data. The company's approach also means inspections can be repeated at regular intervals, allowing changes in seabed state to be monitored over time. With its technology proven in a real-world offshore environment, the Catapult and MarynSol are now working together to survey the opportunities that exist in the ever-growing offshore wind, wave and tidal energy supply chain.

#### 4.1.3 SEAWYND

Following on from the success of SeaSmart, MarynSol has partnered with HydroSurv and ORE Catapult to extend its autonomous inspection and data collection capabilities through the development of SeaWynd.

Offshore wind turbines are exposed to constant corrosive elements as well as varying and extreme mechanical forces from the sea, weather and turbine itself. The remoteness and inaccessibility of these turbines means that maintenance checks are often only performed once a year above water and as little as every five years below water. Therefore, there is potential for significant damage to the turbines during these prolonged intervals between inspections. Current maintenance processes require a manned-survey boat with a highly skilled crew and inspection engineers. Weather and sea conditions can limit the time, or even prevent, the boat staying close enough to complete the inspection. When inspection data is acquired, it is often unstructured, making comparisons to previous data difficult.

SeaWynd is a novel, integrated, multi-sensory platform that will enable the remote inspection of turbine structures, from seabed to splash-zone – the area of the turbine that is periodically submerged below the water line. Deploying the sensor technology on unmanned surface vehicles makes it possible to detect abnormal changes in the structure while also providing a consistent, measurement-based representation of the structure for operators to interrogate.

LIDAR (light detection and ranging) and MBES (multibeam echosounder) equipment are currently used regularly on unmanned surface vehicles to produce a collection of data points of terrestrial land/structures and seabed depth/underwater objects respectively. The SeaWynd project proposed to take these technologies and extend them to produce high resolution 3D surface data for turbine structures – below and above the water line.

The technologies being developed will have several environmental and societal benefits, including reducing costs for windfarm operators and consumers through reduced energy bills. Remote inspections allow offshore crews to work more safely onshore and creates future potential job opportunities in both developing the inspection systems and analysis of the data outputs. MarynSol is using its existing relationship with ORE Catapult to further develop its SeaWynd technology.

### 4.2 ROVCO

ROVCO Invest in R&D to bring the latest in Artificial Intelligence and Computer Vision technologies underwater. Reliable, repeatable and measurable results which improve the knowledge of asset integrity.

The SubSLAM X1 system delivers the highest quality survey data in a fraction of the time it takes to laser scan. Subsea survey and inspections have never been more precise, easy to understand, collaborative, and quick to review.

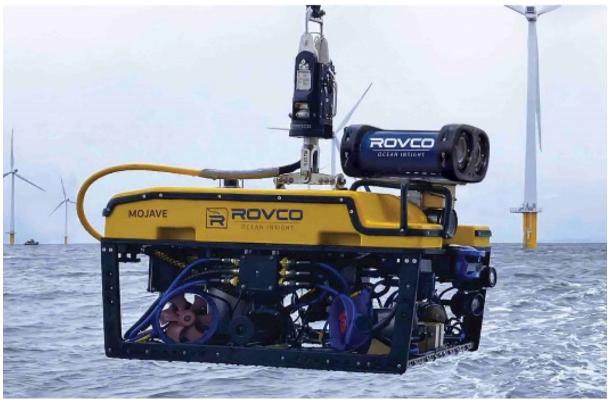

Figure 24 ROVCO Mojave ROV

#### 4.2.1 3D Model With Live Reconstruction

With underwater live 3D, ROVCO provide improved quality ROV inspections. This allows clients to determine problem areas more quickly and provides a better means of communicating information.

#### 4.2.2 Wind Farm Inspection

Rovco have successfully completed an extensive ROV inspection contract. The circa £1 million contract has resulted in completion of the baseline asset integrity survey at the newly constructed Galloper Offshore Wind Farm, a

353MW (56 turbines) installed capacity wind farm which lies 30km off the coast of Suffolk, UK. The project (awarded by Innogy Renewables UK), began in September 2019 – with 24-hour ROV operations provided over a four-week period. ROVCO deployed a Cougar XT ROV fitted with both 3D imaging sonar and SubSLAM 3D technology to complete planned asset inspection activities. The project was performed from the DP2 support vessel, Atlantic Voyager. A second ROV inspection campaign to assess internal foundations is due to mobilise (Jan 2020).

Data for this project is being delivered via ROVCO's in-house Data Command Centre, a proprietary software system which allows for all the various datasets collected to be combined and presented through a simple internet browser. Within the platform, Rovco's clients view survey data libraries, reports, videos and 3D point clouds, as well as utilise intuitive tools to measure point-to-point distances, surface areas and volumes, providing a streamlined workflow for future asset management.

Brian Allen, CEO and founder of Rovco, said: "This project demonstrates the future of offshore inspection. Innogy is the first of our customers to complete a whole field 3D inspection, the data they've obtained will go a long way to enabling and ensuring better asset integrity and knowledge of their infrastructure.

### 4.3 Ocean Infinity

Figure 25 Ocean Infinity "Mothership"

Ocean infinity operate worldwide, collecting high resolution geophysical data from the seabed and water column. They provide a comprehensive seabed exploration system that is highly efficient and permits multi-tasking. Their comprehensive range of on-board systems and equipment permit continuous operation through to project completion, which provides the capability to inspect, repair or recover discoveries made during a survey, eliminating the need for a second vessel. Their approach dramatically increases productivity and reduces downtime – saving clients time and money with their 'one stop shop' multi-purpose vessel.

Capability for accelerated survey periods, multi-autonomous vessel operations and an ability to reduce the carbon footprint of operations through shorter surveying times, use of a single vessel and new electric hybrid engines for new vessels entering construction (new motherships and the Armada Fleet).

Ocean Infinity has applied proven systems at an unprecedented scale on board a single multi-purpose offshore vessel. The technology is precisely integrated into a comprehensive system for offshore survey, inspection, repair and recovery. Recently acquired an additional five Hugin Autonomous Underwater Vehicles (AUV), making a total fleet of 15 which will be powered by Kraken Robotics (TSX-V: PNG) (OTCQB: KRKNF) latest generation long life battery technology. https://oceaninfinity.com/

#### 4.3.2 Armada Fleet

The Armada Fleet: 15 ASV's currently under construction in 2020 with Ocean infinity. Full fleet due for completion in 2021. No Mothership required. ASV's can operate individually or as a fleet. Potential to reduce $CO_2$ emissions of comparable manned missions by up to 90%, utilising electric/diesel hybrid engines.

Figure 26 Armada ASV

### 4.4 Ultrabeam

https://www.ultrahydrographic.com/
High Definition Marine Survey and Inspection. Providing an unparalleled level of detail and precision using innovative survey tools and advanced techniques. Bathymetric Survey, bridge Inspection, Geophysical Survey, Breakwater Inspection, Dock Survey, Harbour Survey, Laser Scanning, ROV Inspection, Wreck Survey, Subsea, Positioning, Unmanned Survey Vessels (Including small DP survey boat).

Key contracts with Ports and Harbors, two offshore wind farms and with network rail (inspection of bridges and infrastructure during or after flooding.

### 4.5 Swaithe and Unmanned Survey Solutions (USS)

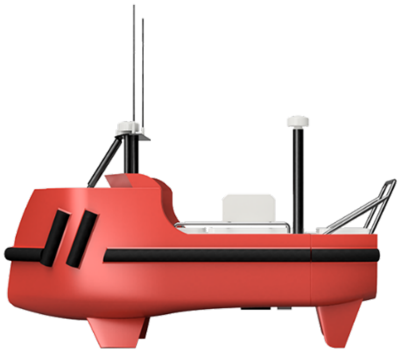
Figure 27 USS Accession class USV

Swaithe are specialists in survey support, providing integrated support solutions for the airborne, land, marine and subsea service industries. Swaithe services provide the equipment, people, expertise and technology to support any survey.

USS design, build and operate USV's. Their modular USV's offer robust, cost-effective and versatile solutions for surveying in all waters from inland lakes and coastal zones to offshore environments. The modular system offers bespoke solutions to meeting client needs. https://swathe-services.com/unmanned-survey-solutions-uss/. The Accession 350 and 425 offer 12 hrs continual operation and carries a SONIC 2024, SBG Apogee Navsight, Valeport MiniSVS and SwiFT SVP. The USV can be operated as a standalone survey vessel or as a force multiplier with a mothership.

### 4.6 Hydrasan Solutions


Figure 28 Hydrasan

Hydrasan Solutions developed an innovative cable condition monitoring technology based on dolphin echolocation technology.
To support the development of Hydrason's technology, testing was successfully undertaken in ORE Catapult's controlled, representative dock environment. This included the burying of cables for an autonomous surface vehicle to detect.

### 4.7 IXBLUE & Drix

A new internationally patented 8m ASV expanding working domains and saving vessel time. An efficient and cost-effective solution compared to traditional ROVs which operate at 1 knt and require more people and logistics. DriX was used in Mexico where it subsequently surveyed 90km of pipeline route at up to 6 knt in the shallow waters off the coast of Mexico to a 25cm resolution. Can provide high resolution imaging 4 times faster than traditional data acquisition by ROV in up to 100m water depths.

It was also proven that DriX offered a carbon footprint 10 times lower than a traditional vessel. https://www.ixblue.com/products/drix

Figure 29 DRIX ASV

# 5 Testing and validation capabilities for RAS

The vital need to have real world facilities to develop, test and evaluate RAS for operation and maintenance functions, especially for harsh and remote environment deployments, is well recognised in the sector[22]. Realistic test scenarios will allow RAS to follow an accelerated development cycle to evolve systems that are robust, trusted and safe and can clearly demonstrate their benefits over more traditional function delivery. The test facilities should be a combination of controlled experimental research labs and 'real' external sites that are as close as possible to real world scenarios. Not only is testing a practical necessity but clear test and validation methodologies will also be needed to enable the advancement of regulations and standards enabling RAS to operate in the real-world environment.

This is not an exhaustive list of test and validation capabilities for RAS but provides a flavor of what is available across Europe and where gaps may lie in meeting RAS sector needs. Whilst some centers specialize in RAS for the ORE Sector there are many crossovers with RAS development in other sectors including health, materials, mission planning and autonomous decision making for example.

### 5.1 Offshore Renewable Energy (ORE) Catapult, UK

The ORE Catapult test and validation facilities provide representative environments to help prove, demonstrate and accelerate the commercialisation of new robotics technologies, increasing investor confidence and bringing their benefits to the market more quickly. Their assets and knowledge have already helped UK innovators like Rovco, Modus Seabed Intervention and Perceptual Robotics take their technologies closer to full commercialisation.

The ORE Catapult recognises that RAS will have an enormous part to play in helping the offshore wind, wave and tidal sectors meet cost reduction, production and productivity targets. This emerging technology area has known potential to create gains in all areas of offshore renewables – from autonomous underwater vehicles that take personnel out of hazardous subsea environments, to sophisticated drones that can perform blade inspections in minutes. With world-leading testing and validation facilities and deep industry expertise, ORE Catapult is leading the way in robotics research for the sector. Alongside their existing assets further test and validation facilities are in development with the Blythe Autonomous Test Site hoping to be operational in 2021/2022.

[22] Heriot-Watt University and Texo Drone, 2018

#### 5.1.1 Marine Robotics & Autonomous Systems Testing

The unique still water dock testing facility features a replica seabed and offers the potential for deployment of scaled and representative offshore wind farm infrastructure, such as cables and foundations, allowing developers of marine RAS to carry out trials in a controlled, representative environment. ORE Catapult's experienced marine engineers and technicians have the capabilities to replicate the conditions found on an offshore wind farm – boosting bankability and investor confidence in innovative solutions that perform well.


Figure 30 NOAH offshore met mast. ORE Catapult

The NOAH offshore met mast is located approximately 3 nautical miles off the coast of Blyth and provides the opportunity to demonstrate marine RAS technologies in real-world operating environments. For example, carrying out a subsea inspection of the met mast foundation and survey of the surrounding seabed using an AUV.

#### 5.1.2 Contact Systems Testing

ORE Catapult facilities provide vast opportunities for the testing, validation and de-risking of systems that come into contact with offshore wind farm infrastructure to perform inspections and repairs. The existing facilities – used for structural and mechanical testing of major turbine components, including blades and drivetrains – can be adapted and used for robotics and autonomous technologies.

The 50m Blade Test Facility provided a controlled environment for the UK SME BladeBug to test its innovative robotic crawler system for surface and subsurface inspection of blades. ORE Catapult's dedicated 27m turbine Training Tower in Blyth provided a perfect platform for Great Yarmouth-based ATAM Group to test the operation of its MagTrack robotic crawler. Furthermore, their 7MW Levenmouth Demonstration Turbine can be used to demonstrate systems in a real-world environment, demonstrating their suitability and readiness for use in the industry.

#### 5.1.3 RAS Instrumentation Testing

In addition to RAS platform testing, ORE Catapult's assets can be used for the development and testing of RAS instrumentation. For example, novel sensors for inspections of turbines and foundations. The Catapult own and operate their own UAVs, which offer aerial platforms for integration with, and testing of, sensing equipment.

The subsea testing facilities have been used by Rovco to test its cutting-edge subsea 3D visualisation systems, which provide offshore wind owner/operators with a clearer – and more immediate – picture of their assets.


Figure 31 Rovco's 3D visualisation system in testing at the Catapult's National Renewable Energy Centre in Blyth.

Beyond the validation of new technologies, the Catapult can objectively assess market potential. They offer independent assessment of the technical and commercial benefits to be gained from using robotics and autonomous technologies developed in the supply chain and academic spheres – for example, their comprehensive O&M cost model can be applied to assess the cost-saving potential of implementing robotic solutions.

### 5.2 European Marine Energy Centre (EMEC)

Established in 2003, The European Marine Energy Centre (EMEC) Ltd is the first and only centre of its kind in the world to provide developers of both wave and tidal energy converters – technologies that generate electricity by harnessing the power of waves and tidal streams – with purpose-built, accredited open-sea testing facilities. Its high energy sites, and access to real-world assets such as marine energy convertors and subsea cables make it an ideal environment for trialling subsea robotic technologies in market relevant conditions.

With 13 grid-connected test berths, there have been more marine energy converters deployed at EMEC than at any other single site in the world, with developers attracted from around the globe to prove what is achievable in some of the harshest marine environments. EMEC also operate two scale test sites where smaller scale devices, or those at an earlier stage in their development, can gain real sea experience in less challenging conditions than those experienced at the grid-connected wave and tidal test sites.

EMEC operates to relevant test laboratory standards (ISO17025) enabling the Centre to provide independently-verified performance assessments, and is accredited to ISO/IEC 17020 offering independent technology verification on marine energy converters and their sub-systems.

### 5.3 Smart Sound – Plymouth, UK

Smart Sound Plymouth is a unique validation and demonstration environment for innovative marine technologies. Covering 200sq miles of water stretching from Looe in Cornwall to the west to Bolt Tail in the South Hams to the East, this area of water provides an impressive variety of water depth, sea states and weather conditions to conduct sea trails. Plymouth Smart Sound encompasses a number of 'in sea' facilities, including the Western Channel Observatory (WCO), which deploys numerous physical assets and brings an unprecedented level of understanding to this environment.

### 5.4 Edinburgh Centre for Robotics, UK

The underlying theme running throughout the centre's research is interaction. The robotics infrastructure includes UAVs, marine technology and immersive virtual reality systems.

### 5.5 UK National Oceanography Centre

The National Oceanography Centre is the United Kingdom's centre of excellence for oceanographic sciences. NOC provides research teams with measurement capabilities via platforms including research ships, ocean observatories, moorings and autonomous underwater and surface vehicles.

### 5.6 The Underwater Centre, Fort William

The Underwater Centre provides training for subsea workers, and supports the subsea industry undertake sea trials. The Facility at Fort William offers a pier-based tidal sea loch location, diving and ROV training areas and multiple subsea test sites.

### 5.7 RoboVAlley, Netherlands[23]

RoboValley drives the development of cognitive robotics by setting up and developing the following initiatives:

- RoboHouse: Companies can discover, develop & test advanced cognitive robotics applications in the smart industry field lab.
- Start-up community: They provide start-ups that want to settle in RoboValley with housing, workspace and funding opportunities.
- Network: Together with their partners, they initiate various activities and programmes to connect all relevant parties working in the field of robotics.

They work closely together with TU Delft Robotics Institute, other experts, entrepreneurs and decision-makers in both the public and private sector.

# 6 Common issues

The market opportunity for RAS is extensive, with very clear intervention areas and market entry points identified in the rapidly expanding ORE sector. Through the research conducted under PERSICOPE and engagement with the RAS industry a number of common issues have been identified that could further accelerate advancement of the sector and realisation of the market opportunity. These subjects have not been investigated in depth as part of this research but warrant mention to support future research activities and potential collaborative solution design. It should also be noted that some of the issues are being addressed through ongoing projects discussed and individual business RD&I activities.

| Issue | Comment |
|---|---|
| Launch and Recovery Systems (LARS) | There is little convergence in LARS for RAS with different systems being utilised or in development, from tethers to optical tracking systems. Connecting two systems in varying states of movement is a significant challenge. Time, method and operating conditions are key. |
| Testing facility access | The UK for example has made significant investments into robotic research, however, its critical supply chains are fragmented into silos of more traditional market applications. This disjointed supply chain is also a product of the lack of large-scale test facilities where these companies and researchers can collectively engage in new technologies within an environment suitable for validation and verification.[24] |

[23] www.robovalley.com

[24] Heriot-Watt University and Texo Drone, *2018*

| | |
|---|---|
| Charging | Issues to address include the need for tethering and/or full recovery with further investigation into surface/subsea charging options and new technologies. |
| Data transfer | Critical considerations around tethering and/or the need for full recovery. Surface and Subsea data transfer methods need further development with key issues around data transfer time, cost and risk as well as on board data storage capabilities and redundancy. |
| Data accessibility | As above with an ideal solution enabling the utilization of RAS and data recovery in expanded weather windows. |
| Accessing real world commercial sites for demonstration and testing. | The maturity of the sector and potentially significant risks to downtime on offshore operational assets limits the current RAS opportunity. Test sites could help to map a commercial development path for RAS linking test and validation directly to commercial site needs and future commercial demonstration. |
| Commercial and investor confidence | Maximising testing, demonstration, validation and operational deployment of RAS will directly impact confidence in the sector. |
| Access to commercial contracts | An increase in confidence in the RAS sector is needed to compete with more traditional means of service delivery from more mature sectors. |
| Regulatory barriers | Regulations and standards have not yet evolved to fully incorporate RAS and data transfer[25]. BVLOS is a critical issue with a significant effect on the market opportunities for RAS. |
| Potential higher upfront capital cost (for equipment) vs lower operational costs | More research and demonstration is needed to validate the long term operational capabilities and benefits of RAS. |

[25] The BSI standards committee on Robots and Robotic Devices and IEEE Global Initiative for Ethical Considerations in Artificial Intelligence and Autonomous Systems (including P7009 standard) are developing for safe and trust inspection of assets with robotics. Within electronic monitoring systems future IEEE standards on embedded systems (P1687) will become compulsory to ensure the quality and insight of the data being sourced for asset management.

# 7 Potential future actions and innovations to support RAS

There is a clear market for RAS in the ORE sector with RAS set to revolutionise O&M processes, driven by the capacity to enable safer and more efficient working practices. Future research will likely focus on the integration, interoperability, validation and deployment of robotic solutions that can operate with existing and future offshore energy assets and sensors, interacting safely in autonomous or semi-autonomous modes in complex and cluttered environments, cooperating with remote operators, able to self-certify themselves and assets to satisfy regulators.

Previous research into the needs for the RAS sector[26], alongside ORE Catapult's industry knowledge has helped to identify key technical priorities and research challenges that could help to support advancement in the ORE sector:

- **Sensing and Mapping** of complex structures using multiple robots equipped with distributed, mobile optical and acoustic spatial sensors and industry accepted non-destructive evaluation (NDE) sensors in the dynamic and challenging offshore environment.
- **Planning, Control, Manipulation** and execution of efficient, localisable and repeatable motion and contact of heterogeneous robotic deployment platforms (wheeled and legged for topside, aerial, marine) for sensor placement and manipulation in extreme and dynamic conditions - with specific emphasis on failure prediction, re-planning and recovery strategies .
- **Intelligent Human-Robot Interaction** and effective communication of world view, system actions and plan failures between remote robot and operator to develop trust and avoid unnecessary aborts.
- **Robot and Asset Self-Certification**, designing robotic systems that can self-certify and guarantee their safe operation including when learning systems are included, predicting and diagnosing faults.
- **Robots operating in different domains working together** – e.g. autonomous surface vessels launching drones; ROVs/AUVs operating from surface vessels
- **Increasing Tooling, Maintenance and Repair capabilities** to enable rapid on site remedial actions. This could include Bolt monitoring/torqueing Nacelle arms and Subsea welding.
- **Predictive maintenance functions**. An intelligent and predictive maintenance regime requires access to the condition of the assets, looking both at data and the knowledge that can be extracted from the data. RAS offer an opportunity to gain extensive data at high resolution in a short time frame and link it to manual interventions and emerging AI to maximise benefits of predictive rather than reactive maintenance.
- **Autonomous residency** – Long term deployment of a fully autonomous solution for wind/tidal/wave farm inspection for example, including docking stations.
- **Utilisation of "eyewear"** enabling instant survey/data access to enable instant reaction. This "hands free" application is relevant to a number of offshore sectors and also has health and safety implications.
- **Motion compensating crane and transfer platform** developments to create a LARS and transfer solution that increases health and safety whilst expanding access windows to offshore installations.
- **Low carbon maritime operations**. The Armada fleet for example predicts up to 90% carbon emissions reductions against standard operation for surveying and data collection. This clear piece of the benefit case could be supported with further research and validation.

[26] Heriot-Watt University and Texo Drone, 2018

- **Mothership development** – Integration of ASV, AUV, Drones, Robots and AI launched and recovered from a single platform.
- **Creation of digital twins** of subsea environments. This offers considerable value as an interface to test and prove systems interaction in a safe virtual environment, increasing confidence and reducing risk. Initially this will likely include combined robotic and manned missions to immerse the operator and build trust leading to fully autonomous control.
- **A new autonomy subsea test site** that has the ability to test and validate subsea technologies with applications across a number of offshore sectors. This facility should also foster a collaborative research approach to maximise shared learning and industry benefits.
- **Addressing regulatory requirements** including BVLOS– RAS's bring the ability to conduct long range activities including Beyond Visual Line of Sight (BVLOS) surveys. This represents a potentially massive benefit for wind farm operations (both in terms of cost and safety). In order to realise this as a mainstream inspection methodology further engagement with the likes of the CAA (Civil Aviation Authority) in the UK and other regulatory bodies will have to be conducted to overcome the BVLOS issue.
- **Innovative Payloads** require further development to adapt to the payload capability of specific RAS systems whilst taking advantage of the multiple sensing potential of RAS. For example, the Anemoi project is developing a specific payload capability to enable the detection of buried cables in offshore wind farms.
- **Resident Systems** need further support to increase confidence in system capabilities and functions and the prosepctive ability for RAS to operate autonomously over extended periods of time.

Figure 32 Anemoi Project. Soil Machine Dynamics

# 8 Conclusions

Clear and quantifiable gains have been identified through the wide-spread adoption of RAS solutions in the ORE sector. The use of AUVs could shave £1.1billion from the cost of operating Europe's 11GW offshore wind farm fleet over the next 25 years with wind farm operators who utilize AUVs reducing their LCOE by 0.8%.[27] An Integrated autonomous ASV could create an annual operating cost reduction of at least £850,000, or £21m over a 25-year operating life for 2GW site according to early assessments[28] The ARMADA ASV fleet has the potential to reduce CO2 emissions of comparable manned missions by up to 90%, utilising electric/diesel hybrid engines.

RAS have the clear potential to positively disrupt survey and O&M practices in the ORE sector by improving response times to faults, improving the quality and frequency of visualisations, inspection and repair, increasing safety levels for human operators and reducing costs of staff deployment. The substantial skills shortage in certain ORE functions at all levels may also be alleviated by the introduction of RAS. At present, limited autonomous inspections in terms of range and mission complexity are possible, though in the next 3-5 years it's predicted there will be an acceleration in capabilities of extended semi-autonomous O&M missions in the ORE market. In the next

[27] ORE Catapult. Avision Project
[28] WASP project, ORE Catapult 2019

10-15 years fully autonomous O&M actions will be a reality with the integration of persistent autonomous robotic platforms.[29]

As discussed there remain significant technical, commercial and regulatory challenges that will need to be overcome to maximise the opportunities for RAS in the ORE sector. Key priorities to address in accelerating this adoption include a focus on investment, new regulatory change, skills development and technology evolution.

Further critical infrastructure is needed to enable more expansive testing, demonstration and validation of RAS systems ideally in a near to real world environment, with potential for progressing from a "digital twin" replication of real world ORE assets and environments to more physical representative assets offshore. The facility should harness the spirit of collaboration, accelerating learning and product development whilst encouraging inward investment. A clear, joined up, service offer from existing facilities could also offer an alternative model to a single centralised site.

An independent, secure data bank for ORE assets is another solution that has been discussed. Though minded of commercial sensitivities, enabling access to critical data sets and models would support accelerated development of the whole RAS sector as well as cost reduction pathways in the ORE sector. It has also been suggested that closer engagement is required in the UK for example with the Lloyds Group, IEEE Reliability and DNV to support the co-creation of regulations that support trusted and safe robot inspections and that could be replicated across neighbouring authorities. These standards will drive supply chain development and help create a clear path to commercial system deployment.

Investment is needed in interlinked basic research and technology transfer to pull advanced robotic technology into offshore engineering, with Industries and Universities working in close collaboration to determine sector support requirements. This relationship should also be extended to other skills providers to ensure the current and future workforce is engaged in appropriate skills development to successfully exploit the opportunities for RAS in the ORE sector.

There are a number of technology enhancements required for the RAS sector to reach its full potential in ORE, with a number discussed in section 7. Advances in sensing and mapping capabilities will be required alongside proven and repeatable planning manipulation and control strategies. The integration of tooling will expand the capabilities of RAS and the services and benefits they can provide, from the removal of marine growth to inspection, management and the remediation of corrosion. Intelligent Human-Robot Interaction will be critical and may be supported by the digitising of offshore assets. Asset Self-Certification provides a key opportunity in the ORE sector with RAS providing the potential ability to predict and diagnose faults, though significant advances in big data analysis may be needed supported by machine learning and artificial intelligence. Data needs to be converted into actionable information presenting a further challenge but this may be alleviated by computational efficient data analysis.

There are clear challenges to address in maximising the potential of RAS in the Offshore and Subsea Energy Sector but the potential gains for both are significant. The Offshore and Subsea Energy market is extensive with fixed and floating offshore wind the current market leaders with very high levels of expected future growth. This growth can be directly supported by reducing the cost and maximising the efficiency of operations which can potentially be delivered by RAS systems whilst increasing health and safety considerations.

[29] Heriot-Watt University and Texo Drone, 2018

# 9 Next steps for PERISCOPE. A cost benefit analysis study for RAS systems.

Many current reports into the benefits of RAS in the ORE sector are based on the assumption that RAS can deliver, a cheaper, safer, less carbon intensive service. Further quantification of these benefits is necessary to provide critical, evidenced based, information to secure backing and investment for the sector and kick start its further evolution. The second stage of the PERISCOPE deep dive activity into the RAS sector will utilise the ORE Catapult COMPASS (Combined Operations and Maintenance, People, Assets and Systems Simulation ) O&M tool to support the case for investment and research backing for RAS in the Offshore and subsea Energy Sector.

The main objective of this activity is to carry out case studies that assess certain ORE O&M practices, comparing cost, time, Health and Safety (H&S) risk and carbon emissions of known practices against RAS solutions. These comparisons will focus on the areas of subsea inspection and maintenance and aerial drone inspection for floating wind and wave assets, which form deep-dive areas of interest within the PERISCOPE project. It is anticipated that these case studies would support the case for progressing the level of RAS action for vehicle applications in ORE O&M. The outcomes will assist potential new funding applications to support autonomous solutions for the Marine Renewable Energy sector, by providing clear quantitative evidence for their implementation.

### 9.1 The scope of the works includes actions to:

- Define a hypothetical floating wind and wave farm baseline installation case studies in the North Sea for analysis (including characteristics such as site capacity, number of assets, distance from shore…etc.)
- Develop a portfolio of notable O&M tasks (scheduled and unscheduled) specific to floating offshore wind and wave renewable energy sites, using transferable tasks from fixed-bottom wind as an initial framework. Activities will be categorised by main component subsystems. Subsystem failure rates are used for characterising unplanned visits.
- Determine the specific activities that could be attributed to (RAS) Robotic and Autonomous Systems in either the aerial or subsea inspection and maintenance environmental domains.
- Configure ORE Catapult's COMPASS tool for the examination of the floating wind and wave farm applications. The tool will assign attributes (labour, equipment/consumables, vessel and downtime requirements) for each task from the portfolio, underpinned by external resources such as databases (weather, vessels…) or notable publications.
- Compare cost and emissions of existing practice regimes against the utilisation of idealised RAS for both floating wind and wave baseline sites. H&S assessment shall be performed comparatively between manual and autonomous operations by evaluating human risk indicators such as total personnel time offshore, number of transfers and number of 'higher risk' operations such as diving.
- Identify potential areas of O&M that would be enhanced with increased automation using these metrics.

On completion this report will be made available through PERISCOPE to the wider RAS and ORE markets.

# Appendix 1 - Current Site surveying robotic technologies

| | Vehicle Parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Manufacturer/ Platform | Length Meters (m) | Width (m) | Height (m) | Diameter (m) | Weight dry, kg | Depth Rating m | Max. Mission Duration – Hours | Available payload power | Payload volume cu. m | Payload weight kg | Mission Turnaround Time | Typical Cruise speed knots | Communications | Vehicle Availability |
| Ocean Server Iver3-450 Nano | 1.6 | 0.1 | 0.1 | 0.1 | 18 | 60 | 10-Jun | 24VDC | - | - | 356 WHrs of li-Ion | 2.5 | WiFi 802.11n Ethernet | C – Commercial |
| Ocean Server Iver3-580-S | 1.5-2.2 | 0.15 | 0.15 | 0.15 | 39 | 100 | 14 | 18-24VDC | - | - | 800-1200 WHrs of li-Ion | 2.5 | WiFi Iridium satellite Acoustic modem | C – Commercial |
| QinetiQ Sea Scout | 0.9 | | | 0.12 | | 200 | | 14VDC | - | - | - | 0-15 Iridium satellite | Radio (VHF) | B – Available |
| Teledyne Gavia Defense AUV | 1.8 | 0.2 | 0.3 | 0.2 | 49 | 500 1000 | 7 | - | - | - | Batteries can be field swapped; 5-6 hours to charge empty to full | 3 | WLAN 802.11G Iridium satellite Acoustic modem | A – Limited |
| Teledyne Gavia Offshore Surveyor AUV | 2.7 | 0.2 | 0.2 | 0.2 | 70-80 | 500 1000 | 4 – 5 | - | - | - | Batteries can be field swapped; 5-6 hours to charge empty to full | 3-Jan | WLAN 802.11G Iridium satellite Acoustic modem | C – Commercial |
| Teledyne Gavia Scientific AUV | 1.8 | 0.2 | 0.3 | 0.2 | 49 | 500 1000 | 6 | - | - | - | Batteries can be field swapped; 5-6 hours to charge empty to full | 3 | WLAN 802.11G Iridium satellite Acoustic modem | C – Commercial |
| YSI EcoMapper | 1.5 | 0.1 | 0.1 | 0.15 | 20 | 100 | 8 | 12-18VDC | 10 inches forward Charge from empty to full | - | 4 to 8 hours to fully charged | 2.5 | WLAN 802.11G | C – Commercial |

| | Vehicle Parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Manufacturer /Platform** | **Length Meters (m)** | **Width (m)** | **Height (m)** | **Diameter (m)** | **Weight dry, kg** | **Depth Rating (m)** | **Max Mission Duration – Hours** | **Available Payload Power** | **Payload volume cu. m** | **Payload weight kg** | **Mission Turnaround Time** | **Typical Cruise Speed – Knots** | **Comunications** | **Vehicle Availability** |
| Atlas Elektronik SeaCAT | 2.3 | 0.3 | 0.3 | 0.3 | 130 | 300 | 6-10 | - | variable | - | - | 314 | Ethernet | C – Commercial |
| BAE Systems Talisman L | 1.4 | 2.5 | 1.1 | - | 50 | 300 | | - | - | - | - | up to 5 | | A – Limited |
| Bluefin Robotics Bluefin-9 | 2.5 | 0.24 | 0.24 | 0.24 | 60.5 | 200 | 12 | 15 W | 0.0025 - | variable -free flooded system | <15 (field swap) 6 hrs battery charge from empty to full | 3 | RF acoustic modem ethernet via shore power cable | C – Commercial |
| Bluefin Robotics Bluefin-9M | 2.5 | 0.24 | 0.24 | 0.24 | 70 | 300 | 10 | - | - | - | - | 3 | RF acoustic modem ethernet via shore power cable | C – Commercial |
| ECA Robotics ALISTER 9 | 1.7-2.5 | - | - | - | 50-90 | 100 200 | 24 | - | - | - | - | 2-3 | WiFi or Ethernet Acoustic Modem Radio (VHF) Satellite link on request | C –I Commercial |
| Graal Tech Folaga | 2 | 0.15 | 0.15 | 0.15 | 31 | 80 | 6 | 12VDC | - | - | 12VDC 45Ah | 2 | 2.4 GHz radio link | B – Available |
| Kongsberg Maritime REMUS 100/100-s AUV | 1.6) | 0.19 | 0.19 | 0.19 | 38.5 | 100 | 8 to 20 | - | - | - | Battery recharge time 8-10 hours empty to full | 4.5 | Acoustic Modem Iridium Satellite WiFi Gateway Bouy | C – Commercial |
| Ocean Server Iver2-580-EP (expandable payload) | 1.4 | 0.1 | 0.1 | 0.15 | 21+ | 100 | 14 | - | 22 inches forwatd | - | 4-8 hours to fully charge from empty to full | 2-Jan | WiFi 802.11G Ethernet | C – Commercial |
| Ocean Server Iver2-580-S | 1.27 | 0.1 | 0.1 | 0.15 | 19 | 100 | 14-24 | 15W | 10 inches forward | 10 | 4-8 hours to fully charge from empty to full | 2.5 | WiFi Iridium satellite Acoustic Modem | C – Commercial |

[30]

[30] Heriot-Watt University and Texo Drone, 2018

# Appendix 2 - ORE Catapult Robotics Projects – Recent and Live

1. **Rovco AUV3D Phase 2** (ORE Catapult were a partner in phase 1)

Bristol based Rovco have developed a stereoscopic AI vision technology to create 3d models of subsea assets. It is ROV mounted, and allows for detailed structural analysis of assets, including accurate point to point measurement in the model. It removes the requirement for watching lengthy ROV captured footage.

Scottish Power Renewables (an offshore wind farm owner/operator) are a partner.

https://ore.catapult.org.uk/stories/rovco/

2. **Safeguard Nautica Phase 2**

Further developing a porotype unmanned surface vessel (USV) for rapid environmental assessment in challenging environments. It can carry a wide range of payloads to form an adaptable platform. The project also seeks to develop a second, larger, unmanned vessel capable of surveying tidal energy and farther from shore sites. The project will demonstrate both vessels in a variety of real industrial sites.

Partners include Safeguard Nautica (lead), Core Blue (a communications technology focussed company) and Reygar (providing vessel control systems).

https://ore.catapult.org.uk/stories/unmanned-surface-vessels/

3. **Bladebug Phase 2** (ORE Catapult were a partner in phase 1)

Bladebug is a crawling robot designed for inspection and repair of wind turbine blades in-situ. To date, robotics in offshore renewable energy has focussed on inspection. Bladebug takes this a step further and aims to demonstrate how robotics can actively maintain wind turbines. Erosion of wind turbine blades is a widespread issue facing the industry.

EDF Energy (a windfarm owner operator) and Imperial College London are partners.

https://ore.catapult.org.uk/stories/bladebug/

4. **RADBLAD Phase 2**

RADBLAD is a robot that will be capable of carrying our radiographic x-ray scans of wind turbine blades whilst in-situ. This will enable understanding subsurface damage that may have occurred within the composite layers of a blade.

Partners are Innovtek (lead) providing data modelling and analysis, and AI software, Forth Engineering who will manufacture the robot, London Southbank Innovation Centre who have extensive experience developing robotics, CIT who develop advanced imaging systems and Renewable Advice, a blade repair and inspection specialist.

5. **MIMRee**

A very ambitious project looking to achieve inspection, maintenance and repair of offshore wind turbine blades using autonomous drones and climbing robots deployed from an autonomous surface vessel (ASV).

Partners include Thales, a global defence company, Bristol, Manchester and Royal Holloway Universities, Royal College of Art, Bladebug, Plant Integrity, whose focus is integrity management and plant inspection, and Wootzano, who specialise in sensors, machine learning, software and robotic applications.

https://ore.catapult.org.uk/stories/mimree/

6. **OSIRIS Phase 2**

A project developing a hybrid system for visual and NDT inspection of wind turbine blades. Visual inspections are first conducted using a drone which can then land on turbine blades to perform contact-based NDT inspections of the blade materials.

Partners include Autonomous Devices (a UK based SME) who are the project lead developing the robotic system, Wood, a leading consultancy to the energy sector who provide an end user perspective and ORE Catapult, who will test and demonstrate the system at their Levenmouth turbine.

7. **Drones for offshore wind O&M**

ORE Catapult have been contracted by the Carbon Trust on behalf of the Offshore Wind Accelerator (OWA) programme to perform a comprehensive review of the potential applications of drones to offshore wind O&M. The term drone for this project captures any robotic/autonomous system that could be applied to conducting an O&M tasks e.g. inspections, maintenance and repair. The OWA is a collection of offshore wind farm developers and Tier 1 suppliers who collectively fund R&D projects which could contribute to lowering the Levelised cost of energy of offshore wind.

# Appendix 3 - ORE Catapult, UK - Project portfolio

### 9.2 Perceptual Robotics

https://ore.catapult.org.uk/stories/perceptual-robotics/

### 9.3 WASP

https://ore.catapult.org.uk/stories/wasp/

### 9.4 iFROG

https://ore.catapult.org.uk/stories/ifrog/

### 9.5 AVISION

https://ore.catapult.org.uk/stories/avision/

### 9.6 Anemoi

This project is developing an underwater vehicle capable of tracking buried (and unpowered) cables and carrying as well as diagnosing some cable fault modes.

### 9.7 Drone Trials

In Summer/Autumn 2018, several drone inspection companies trialled their technology at the 7MW Levenmouth Demonstration Turbine. This kickstarted the work we are undertaken in developing industry standards and guidelines for drone inspection in offshore wind.

### 9.8 Offshore Robotics for the Certification of Assets (ORCA).

The ORCA Hub is an initiative that brings together internationally leading experts from 5 UK universities with over 30 industry partners. Led by the Edinburgh Centre for Robotics (Heriot-Watt University and University of Edinburgh), in collaboration with Imperial College, Oxford and Liverpool Universities, this multi-disciplinary consortium brings its unique expertise in: Subsea, Ground and Aerial robotics; as well as human-machine interaction, innovative sensors for Non-Destructive Evaluation and low-cost sensor networks; and asset management and certification. The project is supported by £14M of EPSRC funds and £17M of industrial consortium contribution. [https://orcahub.org/]

### 9.9 Holistic Operation and Maintenance for Energy from Offshore Wind Farms (HOME-Offshore)

Brings together experts from the universities of Manchester (project lead), Warwick, Cranfield, Durham and Heriot-Watt University. The project is supported through £3M of EPSRC funds and £1M industrial contribution started in 2017. The researchers will create remote inspection and repair technologies using robotics and autonomous systems to inspect the condition of subsea power cables, identify problems early and ultimately, extend their lifespan. [http://homeoffshore.org/]

. Part of the scope is to down select 5 crucial industry challenges. Part of the work is

### 9.10 OWA (Offshore wind accelerator) on robotics.

Includes a (very) broad study that investigates potential Robotic and Autonomous solutions (RAS) for offshore windfarm O&M

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