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APPLICATION OF UNCREWED SURFACE VESSELS THROUGHOUT THE LIFE SPAN OF FIXED AND FLOATING OFFSHORE WIND FARMS

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ABSTRACT

The Offshore Wind sector is seeking to utilise Robotic and Uncrewed Systems (RUS) to help reduce the costs, emissions, and risks of harm to personal associated with the necessary survey and inspection works required over the whole life of fixed and floating offshore wind farms. New wind energy projects are being built in locations further from onshore support bases than previously, and this can impact the level of accessibility for routine and unplanned works, leading to increased use of offshore support vessels and a drive towards automating tasks if possible.

The purpose of this paper is to provide an overview of RUS technology to give potential adopters and end-users insight into how and why different RUS types may be required (working individually or cooperatively) across the whole life of a wind farm.

A review was conducted of the available RUS technology and its suitability for different tasks encountered throughout the initial development, construction, operation, and decommissioning of offshore wind farms. Uncrewed Surface Vehicles were identified as being both well-established multi-purpose data gathering platforms as well as being able to support other RUS above and below the waterline for survey and inspection roles, and considered that this RUS type represents a vital asset for the offshore wind farms of the future

Keywords: Offshore Wind, Floating Offshore Wind, Robotics, Uncrewed Surface Vessels, Collaborative Robotics, Inspection, Resident Systems

NOMENCLATURE

AUV	Autonomous Underwater Vehicle
CTV	Crew Transfer Vessel
FOWT	Floating Offshore Wind Turbine
GNSS	Global Navigation Satellite System
HUV	Hybrid Underwater Vehicle
LARS	Launch and Recovery System
NTM	Notice to Mariners
OWF	Offshore Wind Farm
RUS	Robotic and Uncrewed Systems
ROV	Remotely Operated Vehicle
SOV	Service Operations Vessel
UAV	Uncrewed Aerial Vehicle
USBL	Ultra Short Base Line
USV	Uncrewed Surface Vehicle
UXO	Unexploded Ordnance
WT	Wind Turbine

1. INTRODUCTION

This work explores how robotic and uncrewed systems (RUS) can be applied across the whole life cycle of offshore wind farms (OWFs) from initial scoping work, construction, operation and through to eventual decommissioning or repowering. It considers issues related to relevant work on the wind turbines (WTs) themselves as well as in the wider area of sea and seabed around them that contain the critically important inter-array and export cables that link the WT to the necessary substations and provide a route for electricity to be exported to shore.

There are several reasons behind this approach. The first is that failures of either the inter-array or export cables in this wider area are reported (in 2018) to account for 75-80% of total offshore wind insurance claims, but only around 9% of the overall cost of the project [1]. In 2021 Ørsted announced that multiple cable repairs and additional cable protection was needed at several their OWF [2], and that remedial works would cost almost half a billion dollars. Failure of components on a single WT will only affect generation from that device, whereas issues with cables can potentially affect the whole OWF. The second is security in the face of potentially deliberate actions that may damage OWF infrastructure such as have been highlighted by the NATO Energy Security Centre of Excellence, and by the Global Underwater Hub [3], [4]. Airborne and seaborne RUS are likely to form part of a marine domain awareness solution to detect potential threats [5]. The third is that the construction and operation of OWF is not free from potential detrimental environmental impact [6] such as suspended sediment and habitat loss caused during the seabed preparations needed prior to cable laying and trenching [7], high intensity acoustic energy that can affect marine mammals and cetaceans caused through the "neutralization" of unexploded ordnance (UXO) in the construction area [8] or from piling activities [9]. Even the gathering of data to support studies (required through project scoping through to eventual decommissioning) has an environmental impact including the carbon emissions associated with the multiple crewed vessels used by specialist companies and organizations for work such as vessel traffic surveys, the deployment and servicing of metocean sensors [10], or the repeated observations to record marine mammal and bird populations in the vicinity of the OWF [11].

The paper consists of an exploration of the trends in OWF development that are drivers of the increased adoption of RUS; a review of the primary RUS technologies currently or soon to be employed as well as existing methodologies; and exploration of how RUS operations are evolving to include hosting and deployment of one RUS type by another to minimise the need for crewed vessels in the wind farms of the future. If the use of crewed vessels can be minimized, there are likely to be important benefits to the safety of personnel as well as in the reduction of vessel associated emissions as will be discussed in the following section. Throughout the paper, tasks, and likely roles for RUS in OWF will be introduced as relevant.

2. OWF DEVELOPMENTS AND ACTIVITIES

OWF developments have moved from the near-shore, shallow waters using bottom-fixed WT using monopile or jacket structures, to locations in deeper waters (typically further from shore) that require the use of floating WT (FOWT) based on (for example) semi-submersible platforms with multiple seabed anchors, as well as increasing use of Service Operation Vessels (SOVs) as a local base for technical support. Figure 1 shows locations for OWF around the UK colour coded by status (reported or assumed) as of May 2023 [12]–[14]. It can be difficult to assess movements of equipment and personnel associated with OWF to establish related costs and emissions based on a metric such as distances from an OWF to shore, as the situation will vary on a case-by-case basis and additional information on actual vessel movements is required.

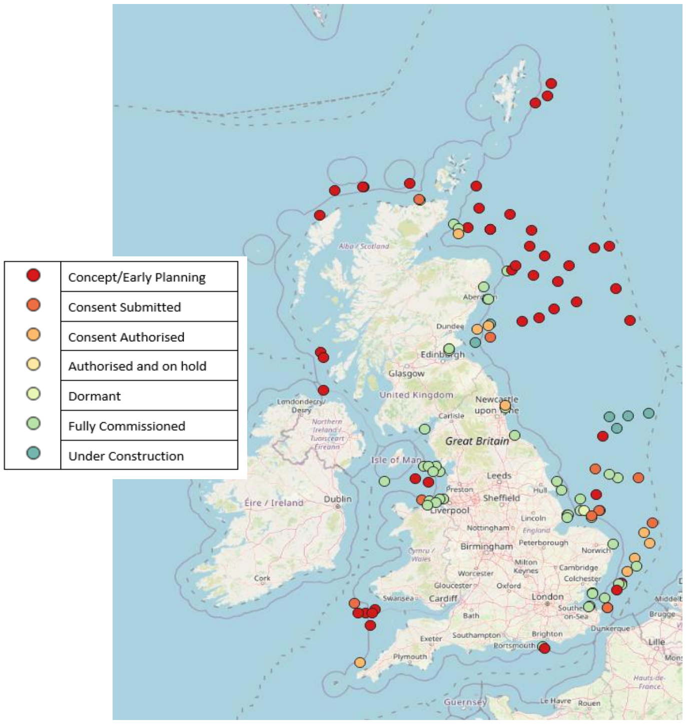

FIGURE 1: INDICATIVE LOCATIONS FOR OWF IN UK WATERS BY STATUS (MAY 2023)

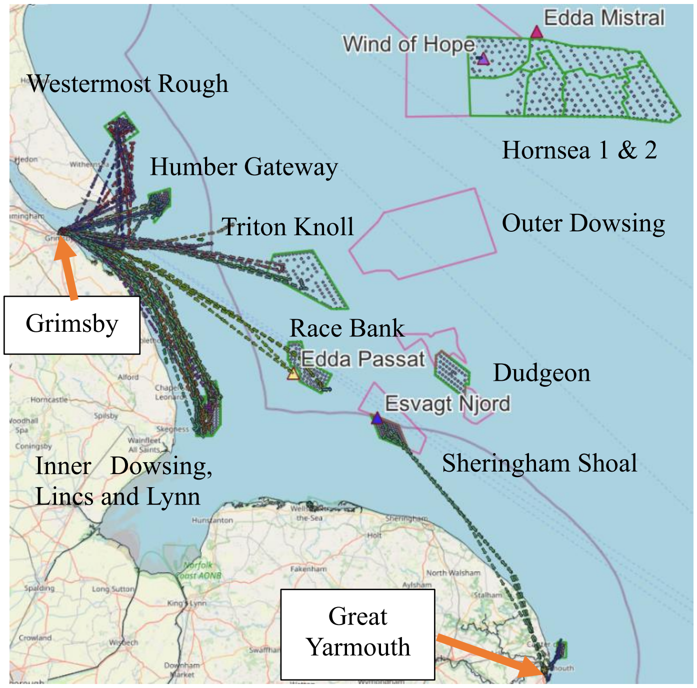

FIGURE 2: CTV AND SOV POSITIONS AS REPORTED VIA AIS AND SOURCED FROM MARINE TRAFFIC (28-30/6/2023)

Figure 2 shows crew transfer vessel (CTV) activity sampled every 90 minutes using Automatic Identification System (AIS) data for three days in June 2023 [15], plotted with OWF boundaries [16] and WT positions [17] using QGIS [18] for an area off the East coast of the UK. Commissioned and operating OWF are shown with green outlines, and those in planning are in pink. The graphic shows that as distances from port increase, as does the likelihood of an SOV (shown as triangles) being present. SOV will either use helicopters or return to port for personnel exchange on a regular basis (as is the case for the SOV on the Hornsea OWF projects), or be serviced by CTV such as at Race Bank, Dudgeon and Sheringham Shoal [19]. The situation may change over time as the OWF matures or the operating company rationalizes its inspection, maintenance, and repair (IMR) provision such as with the use of regional hubs. An increased distance to shore prolongs the duration of any required travel from port to the OWF and impacts the accessibility of the wind farm, particularly during the operational phase when IMR activities require transfer of personnel to the turbines. These factors affect vessel-related costs and emissions [20] associated with energy production as well as exposing personnel to greater risks of harm caused during transits [21].

Typical IMR includes the planned and unplanned work activities that take place on the WT and offshore substations by the technicians of the OWF and other contractors during the operational phase. An unpublished analysis of activities at an OWF in UK waters was conducted [22] that showed IMR works undertaken included periodic inspections to meet the requirements of statutory authorities and turbine manufacturers; blade inspections; foundation inspections; checks and maintenance on generation components, hydraulic systems and electrical transformer and switchgear; fault-finding; and the assessment and repair of damage.

The G+ Offshore Wind Health & Safety Organisation conducted a study into hazards related to FOWT and noted that the motion characteristics of FOWT are highly sensitive to local metocean conditions and that access for IMR will be limited to benign conditions compared with bottom-fixed WT [23]. Safety and operational effectiveness during IMR activities on FOWT that involve working at height such as blade inspections will be impacted due to the dynamic motion imposed by even small oscillations of the FOWT as the motion will be amplified at the working height due to the lever-arm effect. In the description of a study of access for IMR to FOWT it was noted that wave heights affect only access to bottom-fixed wind turbines, whereas the dynamic motions for FOWT mean that wave action will affect both access (transferring from a vessel to the FOWT) and conditions when working on the FOWT [24].

Data on survey operations in OWF can be found in the Notices to Mariners (NTMs) that are published by the OWF concerned to warn other sea users of potential obstructions, restrictions, or hazards. For the waters around the UK and off Northern Europe there is no central repository of this information, but a database is maintained by the Kingfisher Information Service [25]. Examination of NTMs identified survey activities covering the wider sea area of OWFs including the export cable corridor, including environmental studies, resource and metocean assessment, geophysical and bathymetric studies, and the detection and identification of objects on or buried in the seabed such as boulders and UXO. Increased depths affect survey methodologies as sensors are selected based on their effective working range and the resolution achievable with respect to that specified by the client, and so deeper waters can require a change of sensor and/or technique to ensure effectiveness [26].

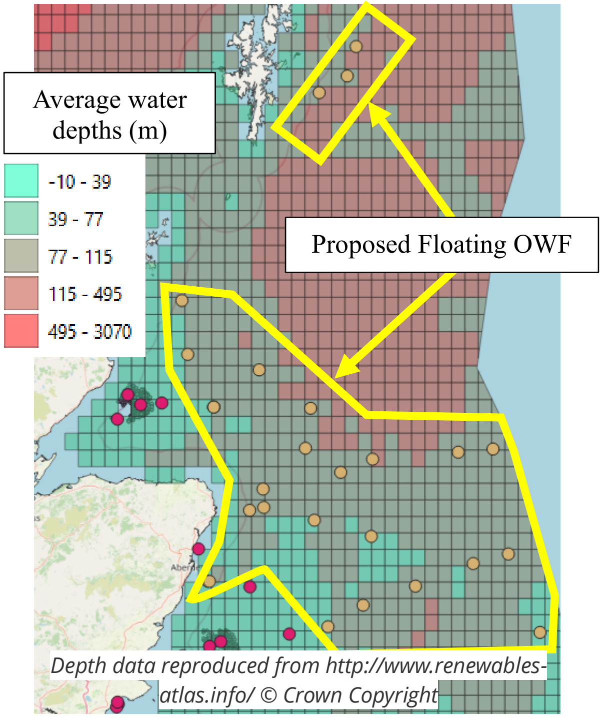

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FIGURE 3: INDICATIVE LOCATIONS AND AVERAGE DEPTHS FOR FIXED AND PLANNED FLOATING OWF

Figure 3 shows an extract of the same data set of indicative OWF positions used for Figure 1 classified as either fixed (red icons) or floating (yellow icons), against average water depth data [27]. It shows that for the plans currently publicized, and other than existing demonstration projects, FOWT off the east coast of Scotland will be in locations with average water depths of between 77 and 115 m. This is not significantly deeper than the fixed OWF in UK waters in terms of the capabilities of vessel-based bathymetric sensors [28] and it is likely that the same methodologies will apply to both. However, in countries such as Norway that have deeper waters close to shore, proposed potential locations for FOWT include those with depths as great as 658 m [29] and so surveys may utilise subsea RUS as part of the data gathering process as well as surface vessel based systems.

3. Existing RUS Technology

A review of the existing RUS was conducted [30], and this found that there was now a wide range of technology that is relevant to

OWF and that operate in air, on or in structures, or at or below the water surface. These are graphically summarised in Figure 4 and their key characteristics listed in Table 1. This section describes each of the primary RUS types and the conventional mode of operation as related to OWF. Though included in the graphic and table for completeness, the RUS types referred to as climbing or crawling robots and remote tooling are not discussed further as they currently require human presence for handling and deployment so not yet able to provide the sought for reduction in use of crewed vessels. However, the review identified that only these RUS types are physically capable of performing maintenance and repair works on the WT and the components thereof, and so may form part of future RUS-based IRM.

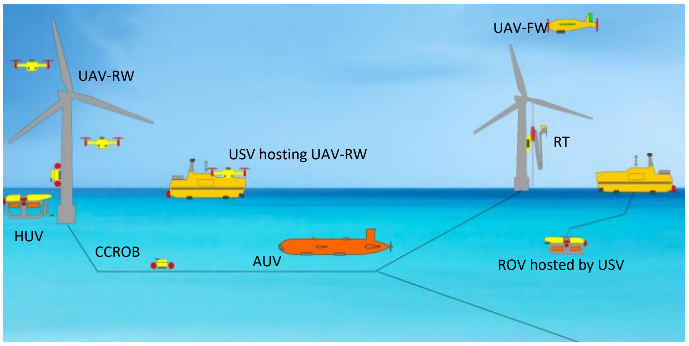

FIGURE 4: ROBOTIC AND UNCREWED SYSTEMS FOR OWF

RUS acronym	*RUS Description*	*RUS Environment*	*Tether*	*Station-keep*	*Manipulator*	*Tooling*	*Telepresence*
AUV	Autonomous Underwater Vehicle	Underwater	N	N	N	N	N
HUV	Hybrid Underwater Vehicle		O	Y	O	O	P
ROV	Remotely Operated Vehicle		Y	Y	Y	O	Y
UAV-FW	Fixed-Wing Unmanned Aerial Vehicle	Air	N	N	N	N	Y
UAV-RW	Rotary-Wing Unmanned Aerial Vehicle		N	Y	P	P	Y
USV	Uncrewed Surface Vehicle	Water surface	N	Y	P	P	Y
CCROB	Climbing or Crawling Robot	Inside or on structure	O	Y	O	O	Y
RT	Remote Tooling		O	Y	O	Y	Y

Y = Yes (typical), **N** = No, **P** = Possible, **O** = Optional
Tether = Physical link (cable) for control and sensor transmission and/or electrical power.
Manipulator = device by which the RUS can grasp and interact with an object ("robotic arm")
Station-keep = ability to maintain position relative to a coordinate or other object.
Tooling = Equipment used to effect work such as cleaning or repair.
Telepresence = ability to provide real-time or near real-time visual imagery and sensor data.

TABLE 1: ROBOTIC AND UNCREWED SYSTEMS FOR OWF - TYPES AND CHARACTERISTICS

Autonomous Underwater Vehicles (AUV) are untethered battery powered vehicles with sufficient onboard autonomy to bring survey sensors to the optimum altitude above the seabed, follow a pre-planned mission route, adapt the mission plan to compensate for greater than expected currents or to ensure that the survey area is completely mapped with good quality data. Positioning quality requirements for subsea surveys are high, and the AUV will be partnered with a vessel that will provide a source of suitable positioning. AUV cannot hold position or maneuver in relation to inspection targets, and there is no real-time transfer of imagery or large amounts of acquired data possible using currently available acoustic communications technology over realistic ranges. AUV have been extensively used by the energy and research sectors for conducting surveys that would be difficult to conduct by any other means such as in very deep water [31] or under ice [32]. They are also used by the military sector for mine-countermeasures surveys [33], [34]. The onboard sensors used in these applications are the same as would be required for geophysical and UXO surveys [35], [36] required during OWF project scoping and construction phases, or during post-decommissioning clearance verification.

Hybrid Underwater Vehicles (HUV) are battery powered and can operate with or without a communications tether. They do not have the mission range of a dedicated survey AUV but are capable of fine maneuvering as per remotely operated vehicles (ROV). Inspection missions can be planned and performed autonomously or controlled in real-time via a lightweight tether (that provides live imagery) to a surface vessel. Specific applications for HUV are still emerging but are likely to involve tasks that combine elements of both AUV and ROV operations such as the inspection of multiple FOWT mooring lines and the in-water sections of the inter-array cables. These tasks would include a combination of slow-speed movements and then relocation to a new start point to repeat the process (either on the same FOWT structure or on the next device). Navigation whilst performing the inspection would incorporate simultaneous localisation and mapping based on visual imagery and sonar sensor input [37]. An alternative is for an RUS to attach to the object being inspected and traverse along its length before detaching [38], but there may be obstruction from the buoyancy modules that support cables and mooring lines. HUV can be equipped with tooling that will enable them to perform measurements of mooring chains at critical points as well as perform visual recording [39]. HUV have already been used for depth of burial surveys along OWF cabling [40].

Fixed Wind Unmanned Aerial Vehicles (UAV-FW) are used to provide environmental monitoring during the scoping phase as a platform for the detection of marine mammals [41] at the surface and for studies of avian population and migration. They can also provide a means of remotely maintaining surveillance on the OWF and the surrounding sea area for unauthorized activity or for search and rescue applications [42]. UAV-FW are based ashore as they require suitable facilities for launch and landing. A variant that allows UAV-FW to have the same vertical launch and landing capabilities as rotary-wing vehicles is emerging as a means of conducting logistical operations for OWF [43] such as the rapid delivery of spare parts to technicians based on an SOV.

Rotary Wing Unmanned Aerial vehicles (UAV-RW) are used to perform inspections of blade and other in-air and accessible surfaces as an alternative to using rope-access personnel. UAV-RW inspections can reduce costs by up to 70% and decreases revenue lost due to down-time by up to 90% when compared to conducting the work using conventional rope-access techniques [44]. UAV-RW can provide remote inspectors with a high degree of "telepresence" as they can use radio-based communications to transmit high-definition imagery and associated sensor data in real-time. However, current UAV-RW used for external WT inspections typically only have an operational endurance of under an hour [45], require human action to exchange the batteries and are only used when in visual line of sight. Whilst there have been great developments in levels of autonomy to allow the UAV-RW to self-position with respect to the target structure and perform a predetermined inspection routine, there is still a need for a crewed vessel to reach the OWF [46] and to act as a base for the pilot(s) and any inspection observers needed to assess the quality and usefulness of the acquired data, and also to direct the UAV-RW towards any locations that require additional attention.

Analysis of operations at a fully commissioned and operational UK OWF [22] indicates that as well as the vessel crew (minimum two) and the UAV team, one or more technicians from the OWF can be required to support the inspection process such as liaising with the OWF control centre to stop and then re-start the target turbine. So, although the risks associated with undertaking inspections using rope-access techniques have been negated, and the inspection operation conducted rapidly and consistently using the UAV-RW, there are still multiple persons required to be transported to site with consequent vessel-related costs, emissions [20] and exposure to risks of harm caused during transits [21].

Remotely Operated Vehicles (ROVs) are already used for visual inspections and non-destructive testing below the water line of WT during the operational phase [47] as well as for the routine inspection of inter-array and export cables. ROV are also integral to the scoping and construction phases where they provide a means of gathering observations and samples for ecological studies; for placing and retrieving equipment used to monitor meteorological and oceanographic conditions; preparing, installing (trenching for protection) and connection of inter-array and export cabling; and for the detection, identification, and neutralization of UXO. UXO surveys are often combined with geophysical investigations such as locating boulders that may interfere with foundation or anchor placement or that obstruct cable trenching and may have a duration of many weeks – for example the 2021 UXO survey for the site and export cable corridor of the Seagreen OWF was in the order of 60 days of expected vessel time [48] for the 60 m long Glomar Worker vessel.

ROV differ greatly in size and capability. The ROV used for inter-array and export cable installation and maintenance are very large, specialised vehicles equipped with trenching or other burial/excavation tooling [49]. "Work-class" vehicles are fitted with manipulators [50] and can carry additional payloads such as those used during the neutralization process. The Saab Seaeye Leopard [51] is an example of a work-class ROV used in the construction phase of OWF. A typical "inspection" or "observation-class" [52] ROV suitable for inspections of foundations is the Saab Seaeye Falcon [53]. The smallest ROV can used for inspecting flooded areas inside WT structures [54], [55] as they can be passed through access hatches by hand. ROVs require a host vessel or other platform to provide transport to and within the OWF, to provide a source of electrical power, and to provide a means of accurately obtaining the position of the ROV [56]–[58]. Vessels working with work-class ROV may be designed to host one or more work-class ROV as a primary capability; be adapted and chartered on a long-term basis; or be a "vessel of opportunity" such as a platform supply vessel [59] or other vessel with a suitable working area chartered on a short-term basis as all the equipment can be containerized and transported. Some inspection-class ROV may be hosted aboard smaller vessels such as CTVs.

Unmanned Surface Vehicles (USVs) are already working in the OWF sector conducting cable routing surveys, cable burial depth assessment, and geophysical surveys in the development stage with the X-Ocean XO-450 USV arguably being the market leader in terms of the number of vehicles in operation (excess of 20) and the amount of hours (12,000 in the first half of 2022) worked in OWF surveys [60]. USV can host other RUS as well as operating as a discrete data gathering platform using onboard or towed sensors [61], and can either be launched in port or from a suitable platform offshore. They have sufficient autonomy to follow pre-planned missions and may have collision avoidance capabilities but are (at the current stage of technology and regulatory acceptance) supervised over telemetry links that include multiple means of stopping the vessel in case of an emergency. Optional USV functionality can be added to a conventional vessel through the addition of a suitably interfaced control system, or the USV can be designed to suit the daughter craft [62] LARS present on SOVs [63].

The USV currently in commercial use offshore are predominantly diesel-electric hybrids where a diesel fueled generator charges a battery that then provides power for propulsion [64], [65], with some having additional input from solar photovoltaic panels. Diesel is chosen due to its relatively high energy density and ease of refueling the USV, and although there are still hydrocarbon-related emissions from this approach, they are significantly less than would be required for a similarly capable crewed vessel. Sail/wind and wave powered USV are also available and are well suited to long-term surveillance and environmental monitoring tasks over wide areas [11], although it should be noted that a diesel-fueled USV for metocean and environmental assessment has recently been introduced [66].

4. Outcome and Discussion

The literature covered for this research showed that the current mode of operation for the majority of RUS requires multiple personnel to be present to facilitate deployment, recharging and general support, and this takes the form of a crewed vessel that would provide transport, energy, communications, and positioning (for subsea RUS). However, the research also identifies that USV can support other RUS to overcome some of limitations specific to AUV, HUV, ROV, RW-UAV and so remove the need for the crewed vessel to present for roles such as inspection, as well as being discrete survey assets [67], and the rest of this paper will proceed based on that premise.

USV hosting other RUS - Early examples of USV hosting AUV and/or ROV were developed to conduct mine-countermeasures operations as a means of increasing the distance between the operator and potential threats. Multiple systems comprised of USV, AUV and ROV are being delivered under the SLAMF (Système de lutte anti-mines futur) Future Mine Warfare System Program [68], [69]. The Multi-Platform Inspection, Maintenance and Repair in Extreme Environments (MIMREE) project [70] demonstrated RW-UAV hosting on a USV (including automated landing and takeoff from a moving deck), with inspection operations can be conducted with the pilot and observer based remotely [71] using the USV as a communications hub. Trials in the project also included the transfer of a crawling robot to a turbine nacelle from the USV using the RW-UAV, with the eventual goal of providing IMR. USV were able to deploy and position ROV in the Autonomous Robotic Intervention System For Extreme Maritime Environments (ARISE) project [57], and this concept has reached commercial reality, with the first fully-remotely-controlled USV-hosted ROV inspections for OWF in 2023 by Fugro [72].

Positioning for subsea RUS - The importance of the provision of suitable positioning for subsea RUS cannot be overstated. Without suitable positioning, data gathered by RUS will be of greatly reduced utility, and appreciation of this is required when considering investment in RUS technology. RUS above the water surface (such as UAV-RW) obtain their position using global navigation satellite systems (GNSS) such as GPS, GALILEO, GLONASS and/or BeiDou, with high-precision enhancements available over local radio links [73]. Those operating below the water line cannot utilize GNSS [74] and instead rely on an integrated solution [75] from acoustics-based motion tracking relative to the seabed or structures, on-board inertial measurement units that provide vessel motion and acceleration data, and external sources of position information such as from ultra-short base-line (USBL) acoustic systems.

USBL systems consist of a “beacon” fitted to the subsea RUS, and a “topside” system mounted on a vessel. The topside system will measure relative range and direction to the beacon and compute a global position for the subsea RUS that can then be used to geolocate survey data acquired. Careful calibration procedures must be followed [76] to ensure that the orientation and physical offsets between the different components is accurately known, and are required following the mobilization of USBL equipment on the surface vessel and/or at the start of a period of survey operations and may be repeated at intervals to check for any issues. A USBL-equipped USV can provide positioning for subsea RUS independent of physical hosting and deployment, and this methodology was used by commercial operator Ocean Infinity [77] during previous searches for the lost Malaysia Airlines aircraft MH370 [56], [57] and other projects where AUV were positioned by USV with all the RUS hosted from a large crewed vessel. This approach may be beneficial in the construction phase of OWF as it removes the need for the vessel hosting the subsea RUS to have USBL hardware fitted and calibrated (saving time, as well as fuel costs and associated emissions). For example, during the construction of the Seagreen OWF, one day was allocated to USBL calibrations for Geo Ranger [48] vessel before the start of ROV-based UXO and boulder works. The USV can also be positioned to provide optimized geometry for tracking and minimise signal detection issues caused by the dynamic positioning thrusters used by the host vessel to hold position during operations. An illustrated overview of USBL principles is given in [14].

Regulations for USV – Some USV have received approval from regulators to perform survey and inspections under remote control and/or supervision and not require an attending crewed vessel for the offshore component of such missions [78], but this has typically been agreed on a case by case basis rather than being able to reference suitable national or international regulations. These regulations are in development - the UK Maritime and Coastguard Agency are due to release a new version of their codes of practice for small workboats (up to 24 m length) by the end of 2023, which specifically includes an annex on “Remotely Operated Unmanned Vessels”, and made the draft version [79] of this available as part of a consultation exercise. The International Maritime Organisation (which refers to USV as Marine Autonomous Surface Ships (MASS)) is developing regulations that would encompass a wider range of uncrewed vessels including cargo ships, and a non-mandatory code is expected in 2025 ([80]). Classification societies such as Bureau Veritas and Lloyds Register now have processes in place to certify USV [81], [82], and the Indian Register of Shipping produced guidelines for USV operation in 2021 [83].

Next steps for USV – Developments currently underway include “resident” operations using automated offshore recharging and/or refueling, and an increase of USV size to allow hosting of work-class ROV and to tow a wider variety of sensing equipment. Fugro is developing the Robodock [84] automated docking concept, and an offshore charging system for crewed and uncrewed vessels is being demonstrated at the Lynn and Inner Dowsing OWFs [85]. Ocean Infinity, Sea-Kit, Fugro, Reach Subsea and others are building larger USV [86], [87], possibly including those used for the acquisition of deeper geophysical data [88]–[90] using techniques and equipment adapted from hydrocarbon exploration.

Hydrogen is being proposed as a fuel source for USV [91] and some other RUS [92], and may in future be manufactured in the OWF when demand for electricity to be exported is low [93], [94]. The technology includes combustion engines using hydrogen as well as hydrogen fuel cells that produce electricity

- classification society DNV released a handbook for hydrogen fueled vessels in 2023 that provides a useful overview of how hydrogen can be applied to vessels [95].

5. Conclusion

This work has presented a range of RUS and their likely applications throughout the life cycle of OWF following a review of the available primary and secondary literature. The importance of the secondary literature in capturing the practical processes and systems involved in conducting work in OWF should not be overlooked as these areas would otherwise be opaque to those not already working in the sector. Considered use of industry materials and events enables researchers to maintain currency with both the state-of-the-art and conventional practice, as well as identify potential opportunities for productive engagement with industry, regulatory, certification and advisory bodies. There are potentially significant opportunities to improve the associated emissions, security, operational resilience, and potential environmental effects of OWF through the increased use of RUS, either as discreet individual devices, or as part a heterogenous solution to overcome the limitations of specific types. Although many RUS are already in use in OWF and are at a high technological level, USVs have emerged as key assets for future OWF as they can be used as survey assets as well as hosts for other RUS to enable elements of IMR for fixed and floating OWFs. Experience is now being gained in both individual and heterogeneous RUS operations on a commercial level. It is hoped that this paper will highlight potential realistic opportunities for the inclusion of RUS-based survey and IMR in OWF on a long-term, holistic basis so that the maximum benefits can be realized.

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