# Scope and feasibility of autonomous robotic subsea intervention systems for offshore inspection, maintenance and repair


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ABSTRACT: This paper explores the combined, collaborative operation of autonomous systems for the targeted inspection and intervention in offshore environments in order to minimise manned, at sea, marine operations. The joint operation of Autonomous Surface Vessels (ASVs) and Remotely Operated underwater Vehicles (ROVs) will require artificial intelligence to assess and action any given situation in the challenging marine environment around sub-sea infrastructures.

ROVs are typically controlled by human operators to install, maintain, inspect and repair subsea infrastructures. In specific circumstances these ROV operations are not possible and human interventions in the form of diving operations are necessary. With increased numbers of offshore installations, e.g. offshore wind installations, the need for subsea interventions continues to rise worldwide. The increase in demand for subsea interventions using human operated ROVs or human activities will impact on cost and increases the risk of incidence. As such, dedicated R&D is increasing to develop safe and reliable autonomous solutions to optimize subsea inspection, maintenance and repair (IMR) operations. An autonomous robotic inspection and intervention system would significantly challenge the existing methodologies to increase safety and reduce costs.

This paper reviews existing systems in order to scope and assess the feasibility for a Launch and Recovery System (LARS) that would allow the autonomous, combined operation of an ASV and ROV, highlighting the design challenges and outlining solutions through testing and demonstration in a realistic environment. Suitable mission profiles for offshore renewables are also established and analysed.


## 1 INTRODUCTION

Operations undertaken by Remotely Operated underwater Vehicles ROVs in the offshore wind sector can be divided into five categories: pre-construction, construction, routine inspection, unplanned maintenance and decommissioning. For autonomous deployments, the principal target is routine inspection, where midsized ROVs are used, that can be deployed from available platforms, whereas the construction and decommissioning phases are likely to involve support vessels onsite, lessening the need for autonomous vessel involvement.

The feasibility of autonomous ROV use for offshore inspection depends on the technical as well as commercial feasibility. This paper aims to assess areas where their use will be commercially feasible, carrying out a detailed literature and industry review. The technical requirements for the potential IMR missions are also reviewed in order to inform the design of Launch and Recovery System (LARS) using existing Autonomous Surface Vessels (ASVs). The remaining paper is structured in six sections. A brief review of ROV systems (section 2) is followed by an overview of their potential applications (section 3). In section 4, Existing operations, and Launch and Recovery System types are matched to the different ROVs. Further technical considerations are discussed in section 5, whilst the specific design of an autonomous Launch and Recovery System is outlined in section 6. Finally, the main findings are discussed (sec 7) and the paper concludes with an outlook on further work.

## 2 BRIEF REVIEW OF ROVS

This section briefly reviews currently available ROV types and their typical use for offshore work. Whilst some ROV operations are discussed in the literature, this review also draws on a stakeholder survey for typical use and applications, as well as potential future use of ROVs in offshore wind working environments.

## 2.1 *ROV Operations*

GL Garrad Hassan (2013) identifies areas where ROV are employed for offshore wind Operations and Maintenance (O&M) as: i) export/array cable surveys and repairs and ii) scour and structural surveys. A distance of 40 NM (74 km) from port is identified as the approximate cut-off where crew transfer vessels can no longer be used, and offshore accommodation becomes necessary. By removing the need for large accommodation vessels a step change in O&M vessel cost may be possible.

Early opportunities for this technology are therefore expected for newer wind farms that are further offshore. There are a number of far offshore farms due to be developed such as Hornsea Project One. Figure 1 shows that some 100km+ distance-to-shore installations are already in operation in Germany.

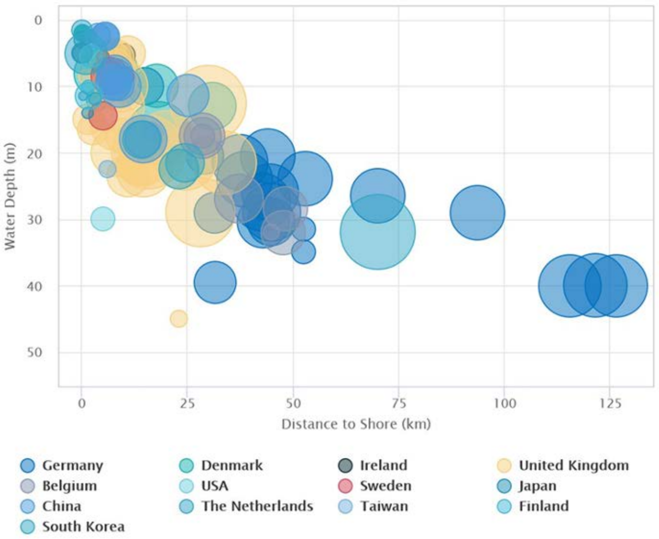


Figure 1. Operational offshore wind farms arranged by depth and distance from shore, Renewables Consulting Group (2018)

## 2.2 *ROV Classifications*

The International Marine Contractors Association (IMCA 2016) has classified ROVs according to their capabilities.

Class I to Class III vehicles are of most interest to this study, whilst future applications for offshore wind may also lie with class VI vehicles. A brief review regarding the capabilities and applications for offshore wind applications is given in the following sections.

Table 1. ROV Classes and description (after IMCA 2016)

| Class | Description |
|---|---|
| I | Pure observation ROVs |
| IIA | Observation class vehicles with a payload option. |
| IIB | Observation class vehicles with light intervention/survey and construction capability |
| IIIA | Standard work class vehicles with a pay-load of <200kg and through frame lift of approx. 1000kg |
| IIIB | Advanced work class vehicles with a pay-load of >200kg and through frame lift of up to 3000kg |
| IVA | Towed vehicles, typically ploughs used in subsea cable burial operations. |
| IVB | Tracked vehicles utilising water jetting and specialised rock cutting tools, again used in the burial of subsea cables and pipelines. |
| V | Prototype or development vehicles |
| VIA | Autonomous Underwater Vehicles (AUVs) weighing <100kg |
| VIB | Autonomous Underwater Vehicles weighing > 100kg |

### 2.2.1 *Class I ROVs*

Class I ROVs (Fig. 2) do not tend to house equipment beyond a camera and sonar, and are versatile for inspection tasks from a variety of vessels. They are small enough to be easily hand deployed, and can even be deployed from an ROV *'mothership'*.


Figure 2. VideoRay Pro 4 Class I ROV (VideoRay 2010)

### 2.2.2 *Class II ROVs*

Class II ROVs (Fig. 3) provide more tooling capabilities and are becoming increasingly able to carry out a number of intervention tasks with tools such as electrical manipulator arms.

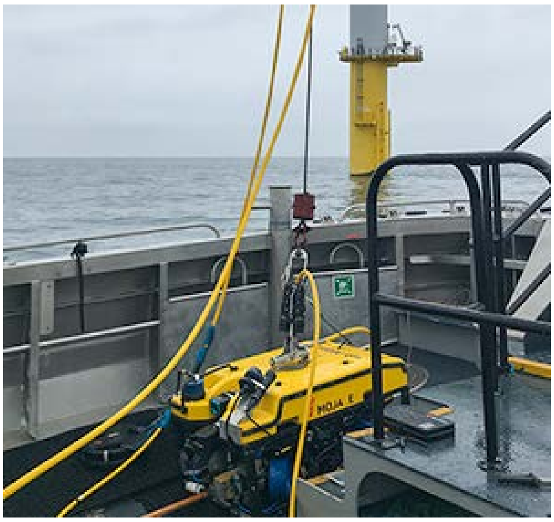

Figure 3. Sub-Atlantic Mojave class II ROV before free-swimming launch (ROVCO, w.y.)

### 2.2.3 *Class III ROVs*

Class III ROVS (Fig. 4) have the greatest range of capabilities, but also the largest topside support requirements. They are the workhorses of the oil and gas industry, and are always deployed with a tether management system (TMS).


Figure 4. Class IIIB ROV example onboard a semi-submersible drilling rig (Fertoing 2013).

### 2.2.4 *Class VI AUVs*

Autonomous Underwater Vehicles (AUVs) are increasingly used for specific, automated observational tasks such as hydrographic surveys. There are also some class VIB (Fig. 5) vehicles under development that have hovering capabilities, extending the possible inspection envelope.

Figure 5. Saab Sabretooth Class VIB vehicle being tested with a subsea garage at NASA Neutral Buoyancy Laboratory (Saab 2015).

Comparing on-board power capabilities, which is important for inspection instruments and tooling, AUVs have higher restrictions than ROVs. AUVs are operating on batteries, with subsea garages (as in Fig 5) under development to recharge and to transfer data. Testing and research is carried out in order to investigate stability under environmental loads, long-distance navigation in shallow water, marine growth, and economics (CAPEX costs). It is not yet known what limitations will be on hovering AUVs attempting to operate in tidal currents.

## 2.3 *Launch and Recovery Systems*

The launch and particularly the recovery of ROVs are amongst the most challenging aspects of their operation. The guidelines by IMCA (2013) state the limiting sea state for ROV launch and recovery systems as $H_S$ = 6m, T = 8-10 seconds. Additional factors including vessel type, currents, wind speed, visibility, and vessel heading must also be considered before launching an ROV. A range of existing Launch and Recovery Systems (LARS) for ROVs are being used in the field. An overview of typical systems is shown in Fig. 6.

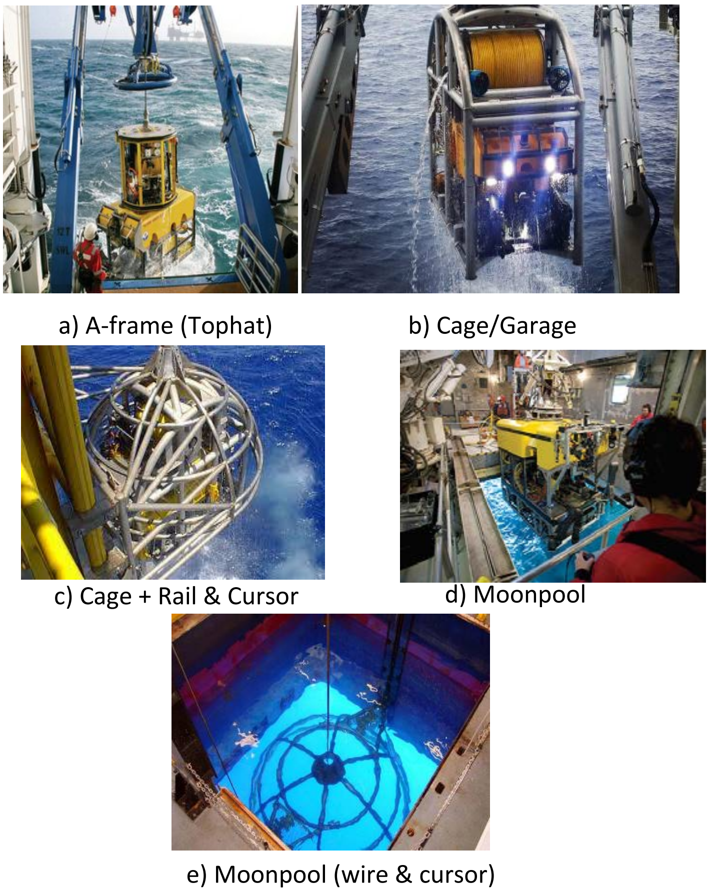


Figure 6. Assortment of Launch and Recovery Systems. Pictures from a) (ON&T 2014); b) (Oceaneering 2018); c) (MarineTech 2015); d) (IMCA 2013); e) (Lauhglin 2010)

Larger class III ROVs will generally employ a TMS housed in a cage, or as part of a tophat. A-frames are commonly used to launch ROVs, though often need close supervision to eliminate risk of excessive ROV motions as it is lifted and lowered.

A moonpool will allow the launch operation from a more stable location on the vessel. Used in conjunction with a rail/wire and cursor it also mitigates the risk of the ROV impacting the vessel, enabling launch and recovery operations in higher sea states.

Alternatively, cranes with optional heave compensation can also be used for smaller Class II ROVS, but require significant human handling/intervention.

## 3 POTENTIAL APPLICATIONS

### 3.1 *Offshore Oil and Gas*

There has been an interest in the use of ASVs to launch ROVs for IMR missions in the oil and gas industry. One major advantage of this is the cost reduction through avoiding the need for asset owners to keep a field support vessel (FSV) on permanent hire. Additional benefits arise from having remote piloting, such as health and safety, administration and logistic challenges arising from potentially having staff work in a separate country.

When there is a large excursion from the launch platform to the subsea asset being inspected, it is not always possible to use a resident ROV and to track the ROV position at large horizontal offsets.

One such operation is pipe-laying, where the chase boat is supporting a pipe-laying vessel, monitoring the pipe touchdown. There have already been operations where this chase boat has been replaced by an ASV. Subsea well IMR can also involve large offsets, where multiple wells are connected to a single platform and would thus benefit from combined ASV/ROV deployments.

In general, autonomously launched ROVs are well suited to short, well-defined projects such as IMR of offshore jackets, or working in unstructured environments, where unexpected obstacles and hazards may need to be avoided.

### 3.2 *Offshore wind*

Offshore wind farms are being routinely inspected for regulatory and condition monitoring purposes. The subsea element of these inspections commonly involves the foundations and submarine cables.

Removing the offshore personnel on offshore wind ROV missions can allow for longer deployments of smaller vessels, removing the need for offshore accommodation, or the need for a daily return to shore. The cost penalties of waiting for suitable weather windows, or sufficient visibility are reduced by removing the need to mobilise offshore teams, incurring labour costs despite no work taking place.

As well as potential cost reductions, there are safety advantages through the reduction of human handling and operations in an offshore environment, in particular through avoiding sea sickness challenges during transfer and operation. Offshore Wind safety reports across the sector (G+ 2016) listed 737 health and safety incidents in 2016, of which 187 occurred on vessels.

### 3.3 *Regulatory and economic context*

At present, little standardisation exists for the frequency and extent of subsea inspections for offshore wind. The German BSH (2015) standards do provide some guidance regarding the minimum inspection requirements for offshore wind support structures (see table 2).

Table 2. Minimum requirements for periodic subsea inspection of support structures from German standards, adapted from (BSH 2015)

| Test Object | Description |
|---|---|
| Functionality of anodes, impressed-current system | Annually (first 2 years), then depending on condition (recommended every 4 years) |
| Welded seams (subject to cyclic loads) | In line with life-cycle calculations and inspection plan |
| Composition of seabed, scouring | Annually (first 2 years), then depending on condition (recommended every 4 years) |
| Corrosion protection (visual inspection): | |
| • Submerged structure | Depending on condition (every 4 years) |
| • Splash zone | Depending on condition (every 2 years) |

Based on these recommendations, an estimate of around 10 subsea inspections over the 25-year lifetime of a wind farm appears reasonable. This assumes an increased frequency towards the end of the asset life as well to support life extension measures. More unplanned inspections may occur following extreme weather events or ship impacts.

Marine growth inspection is undertaken visually using a ruler tool that is manually driven to the foundation and measurements are then taken from the ROV camera.

This process currently requires the skill of a pilot. The increasing capability to deliver accurate 3D imaging of the structure may in future offer an alternative, autonomous, means of assessing marine growth instead.

### 3.4 *Cathodic protection monitoring*

Corrosion protection systems are checked to ensure they continue to operate at the design potential, and hence the structure remains protected. The most common method is to use a probe deployed by a ROV as shown in Figure 8.

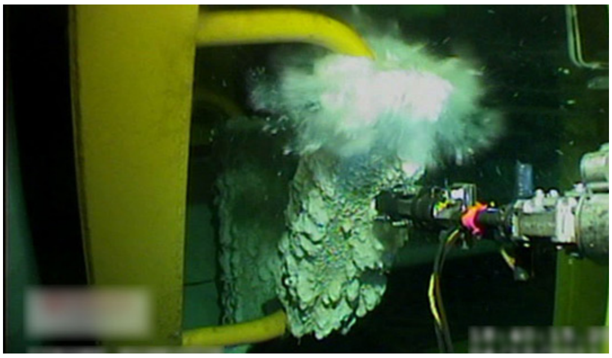

Figure 8. Anode potential being measured using a probe (Polatak, 2018.)

This tooling would be challenging to operate without a remote pilot, so fully autonomous inspection would more likely need to use a field gradient sensor or similar.

### 3.5 *Weld inspection*

Weld inspection is not currently routinely undertaken, and involves challenges such as obstruction due to marine growth. However, possible technical solutions, as shown in Figure 9, are being explored by ongoing R&D projects.

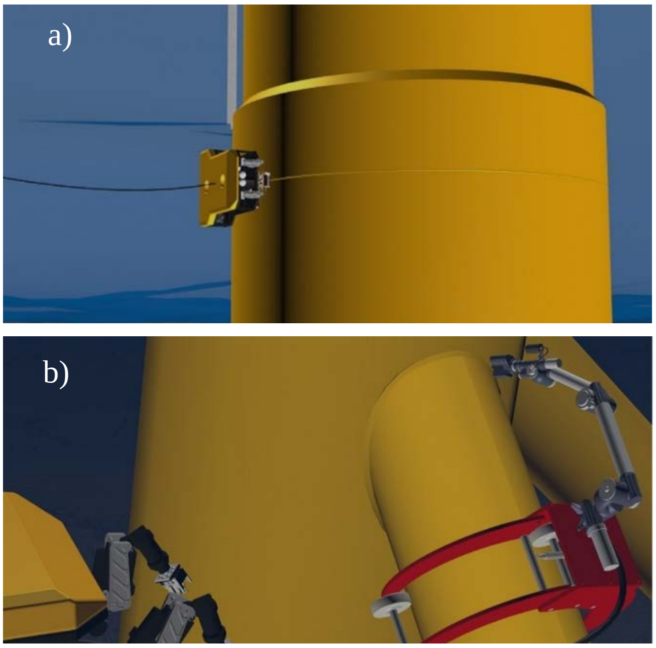


Figure 9. Weld inspection methodologies under research for offshore wind (Maritime Journal 2018) a) monopile crawler ROV b) jacket clamp

Solutions for jackets and monopiles involve tooling being deployed from an ROV. For jackets, a clamp is installed to inspect the node, whilst monopiles use a magnetic crawler. Marine growth is cleaned away before weld inspection, which is possible with a number of ROV tools.

Weld inspection is likely to be most useful for life extension or inspections resulting from suspected flaws of problems in the substructure welds.

### 3.6 *Grout inspection*

Grout inspection methods for monopile and jacket foundations are also under development. This will be especially important for pre-2012 structures, which have experienced issues relating to grouted connections. It is estimated that 35-40% (Carbon Trust 2017) potentially suffer from such issues.

Few details have presently been released about the methodologies, though one proposed solution for monopiles uses a small ROV to inspect the grout internally. The ROV is deployed inside the monopile (Uniper 2018), and therefore it is not likely to be made autonomous, unless other techniques are developed.

### 3.7 *Cable survey*

It is important to ensure that cables remain at the planned burial depth, and are not in danger of becoming exposed or damaged through movement of sediment or seabed activity such as fishing.

There are various cable depth-of burial survey tools available, which require support platforms of different sizes.

The lightest tool is deployed from small class II ROVs, and uses gradiometers that require the cable to be magnetised cable or to carry a tonal signal for detection. This tool has been tested from the Sabretooth AUV (Hydro, 2017).

Other sensors will generally require larger ROVs, and are beyond the size and power capabilities of even the larger AUVs presently available.

These surveys remain important, though the frequency of them may reduce with the rise of interrogation of cables through methods using optic fibres.

## 4 MATCHING ROV REQUIRMENTS WITH LARS AND APPLICATIONS

The choice of LARS should be adapted to suit the class of ROV, common examples of such systems are shown in Table 3. Class I ROVs can often be deployed without the use of a LARS, whilst the largest ROVs generally require a more complex, and dedicated LARS. Though all ROVs can be deployed through a moonpool, the means of lowering the ROV will depend on the class of ROV. AUVs can be lowered into the water in a number of ways, including via a ramp at the stern of the vessel, though recovery is more challenging.

Table 3. Launch and recovery systems by ROV class

| LARS | Class I | Class II | Class III | Class VI |
|---|---|---|---|---|
| Manual | * | | | |
| Crane | * | * | | |
| A-frame | | * | * | |
| Moonpool | * | * | * | |
| Stern ramp | | | | * |

ROVs are used in offshore wind in a variety of ways, and the requirements for different missions are best suited to specific classes of ROV. Table 4 gives an outline of the capabilities by class for a selection of offshore wind activities. Of particular interest is the continued expansion of capabilities in class II vehicles, whose LARS and TMS requirements are likely to be easier to automate.

Table 4. Offshore wind tasks by ROV class

| Task | Class I | Class II | | Class III | | Class VI | |
|---|---|---|---|---|---|---|---|
| | | A | B | A | B | A | B |
| UXO investigation | | * | Y | Y | Y | | * |
| UXO excavation | | | * | Y | Y | | |
| As-laid Cable Survey | Y | Y | Y | Y | Y | Y | Y |
| Cable Depth of Burial | | | * | Y | Y | | |
| Cable pull-in | * | | * | Y | Y | | |
| Marine Growth Inspection | Y | Y | Y | Y | | * | * |
| Corrosion Protection Inspection | | * | Y | Y | Y | | |
| General Visual Inspection | Y | Y | Y | Y | Y | Y | Y |
| Weld inspection | | | ** | Y | Y | | |
| Grout inspection | | ** | ** | ** | ** | | |

* In some cases
** Expected capability

# 5 OTHER TECHNICAL CONSIDERATIONS

## 5.1 *Design Challenges*

Remote piloting in an over-the-horizon configuration holds a considerable control challenge due to signal latency. Piloting support software will have to be used to enable station keeping and auto-transit capabilities, as a remote pilot will not be able to respond to e.g., wave loading with signal latency.

Manual maintenance and supervision of ROV launch operations will also not be possible offshore. Hence testing of thrusters and other systems will need to be automated as far as possible. Autonomous recovery is a particular challenge and requires dedicated technical solutions.

Cable snagging is a risk with any ROV operation, and will need careful consideration, and/or use of sensors / automated tether management systems to mitigate this risk.

## 5.2 *Tether Management Systems*

Tether management is an important part of the task during ROV operation. The most universal system is integrated into a garage as shown in Figure 5b, which can be used for all sizes of ROV. Whilst a Top hat (Fig 5a) is used for Class III ROVs.
Free-swimming ROVs are deployed without a tether management system, and thus caution must be taken to avoid cable snagging.

## 5.3 *Equipment*

For an autonomous marine operation, a capable Autonomous Surface Vessel (ASV) will be required, together with a suitable and correctly sized ROV. An ongoing research project between ASV Global and the University of Exeter considers the design and demonstration of an autonomous LARS. The design considerations, focussing on the autonomous LARS will be described in some more detail in the following.

# 6 DESIGN OF AUTONOMOUS LARS FOR FIELD DEMONSTRATION TESTS

## 6.1 *Autonomous Surface Vessel*

The ASV Global C-worker 7 (Fig. 10) (ASV, 2018) is a 7.2m length autonomous surface vessel, with a moonpool suitable for launching a class II ROV. The technical specifications are: beam: 2.3m, draft: 0.9m, height: 4.2m, weight: 5.3t lightship, propulsion: 2 x20kw electric thrusters with diesel generators and batteries, speed: 6.5 knots, payload power: 2 kW, moonpool: 2.5m long x 1m wide, control: ASView for direct, semi-autonomous or autonomous control.
The size of the vessel and the presence of the moonpool enables the launch of larger ROVs than have previously undergone testing. The deployments would also be possible in higher sea states.

Figure 10. ASV C-Worker 7

## 6.2 ROV

The Seatronics VALOR (Fig. 11) has been selected for sea trials. The 0.81m wide VALOR is well-suited for launch through the moonpool, and the 73kgf forward thrust on a vehicle of this size should aid operability under current loading.


Figure 11. Seatronics VALOR ROV

## 6.3 LARS for field demonstration

The C-worker 7 moonpool is well-suited for deploying a class II ROV. An actuator system will be used to raise and lower the ROV through the moonpool with a winch system used to manage the vehicles tether. Once the ROV is a safe distance below the vessel, a lock latch will release the ROV.



Figure 12. ASV C-worker 7 vessel shown deploying an ROV via a frame through the moonpool. a) side view b) elevation view

Figure 12. Gives an example of another launch configuration which is possible, where the ROV is launched and recovered using a cage.

This is an active area of development for the project which is subject to change as experience is developed within the project.

## 6.4 Tether Management Systems

The Seatronics VALOR ROV is suitable for use in 'free-swimming' mode, and hence the tether will be managed using a topside winch, with no dedicated in-water tether management system. This is suitable for class II ROVs, though the system will be assessed during sea trials. Cage or rail and cursors systems would be considered for larger ROVs.

# 7 DISCUSSION AND CONCLUSION

Opportunities for offshore wind inspection using ROVs lie primarily with routine and unplanned (after extreme weather events) inspections and maintenance. Windfarms located far offshore are likely to be the first adopters of this technology. For continued development, it will be necessary for asset owners to consider and accept fully-autonomous vehicles navigating the vicinity of their structures. Possible design solutions include resident AUVs with subsea garages, as well as mission deployments of AUVs.

Pre-construction activities such as surveying may be undertaken by AUVs or remotely launched ROVs. Table 4 shows that some of these activities, such as UXO excavation are generally undertaken by class III vehicles. The LARS requirements will be more challenging and thus require more resources & development for remote launch.

As ROVs and respective tooling continues to develop, the industry continues to strive to do 'more with less', making more tasks possible with smaller ROVs. Pre-construction tasks such as geotechnical coring may become possible with an autonomously launched class II ROV.

Missions during the construction phase generally involve large vessels such as jack-ups or cable-lay vessels, and may therefore be platforms for early adoption of ROV support from an ASV to minimise the use of other infield vessels. For example for tasks with a large ROV excursion from the construction vessel. Additional cost-savings may be possible, if construction vessels could continue onto other tasks.

Work in unstructured environments such as decommissioning or post-storm inspections are well-suited to autonomously deployed ROVs. A remote pilot can avoid obstacles or hazards whilst keeping crew away from more hazardous environments.

Autonomously deployed ROVs are a technically feasible proposition for the offshore wind sector, initially using Class IIA ROVs, to reduce cost, as well as Health and Safety risks for personnel.

Research developments in this area will be governed by the commercial need for autonomy. With various technological options under development, it is not yet obvious which technologies are most likely to become adopted for industrial and commercial settings.

The stakeholder survey carried out for this paper provides useful insights into this emerging field, gathering the views across suppliers, developers, and customers; though sampling a large sector provides a snapshot of industry opinion, as the complete picture continues to develop.

The commercial and technical challenges have a challenge to phase the developments. With AUVs and ASV-launched ROVs being developed in parallel, users may 'hesitate', at the expense of the development of both autonomous systems. This highlights the importance of research in this area and the need to address and to mitigate 'first-mover' risks.

As part of planned further work, the autonomous system described in section 6.3 will undergo a controlled field demonstration at Falmouth Bay Test Centre (FaBTest) in Cornwall, UK. The primary objective is the operational trial and demonstration of the launch, recovery and operation, using an ROV from an Autonomous Surface vessel.

The testing will assess the suitability of the LARS and tether configurations proposed, as well as investigating the operation of tools, and piloting of the ROV from a remote location.

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