1.1 Project Overview
Over the past decade, there is a growing interest from investors on the development of offshore wind farms, which in turn has contributed to the rapid development of this industry (Irawan et al., 2017). However, due to the requirement of wind farms installation to be within the pathways of high current winds – a unique environment characteristic by itself – this introduces a lot of challenges in the operations and maintenance activities (O&M). O&M activities account for a quarter of the life-cycle costs of a wind farm (Snyder and Kaiser, 2009), and hence, overcoming the challenges of O&M directly lowers the cost of energy from offshore wind farms and also increases the reliability of offshore wind farms.

The main maintenance activities within a wind farm can be divided into the three following categories; service maintenance; proactive (or preventive) maintenance; and corrective maintenance. Although service maintenance is planned as a yearly activity, it is fairly common that the yearly corrective actions of a turbine can take between three to four visits per annum, due to its unpredictable malfunctions (Röckmann, Lagerveld and Stavenuiter, 2017). Moreover, a proactive maintenance of each tower also requires multiple visits every year.

Accessibility has been seen as the most significant barrier that is currently being faced by offshore wind maintenance teams. Because of the far distance from shores and also harsh environments, accessibility is always an issue for maintenance teams. Therefore, maintenance cost and time can be reduced by increasing the accessibility of the farm. Moreover, this can also lead to the longer uptime of wind farms. The use of Autonomous Vehicles (AVs) can therefore potentially provide us with the opportunity to increase the efficiency of accessibility (Shukla and Karki, 2016).

Human errors and unexpected problems have also resulted in the unavailability of required parts or tools, which can interrupt the maintenance and repair activities. Moreover, inspections of different parts of the wind farm from turbines, foundations and cables are crucial in determining the required future activities. A recent study has proven that the application of AVs can help operations within this realm of problems (Moir, 2017). The main objective of this study is to investigate the potential use of AVs for parts and tools delivery in the Operation & Maintenance (O&M) activities of offshore wind farms.

This study identifies various possible areas, in which the application of AVs and also UVs (Unmanned Vehicles) can add a value to the lifetime asset management within a wind farm. The following points are covered in the main report include:

- Review of recent innovations with regards to AVs and UVs technologies in offshore industries (i.e. offshore wind and offshore oil and gas).
- Investigating the current procedure of the O&M activities, including the type of workforce involved, the planning process and the most common equipment used to access the inspection or repair target.
- Recognizing the barriers and limitations of O&M activities, requirements of the industry and opportunities to improve the logistics activity through the use of AVs.
- Proposing innovative approaches to AVs usage within different O&M activities, starting from inspections to parts and tools delivery, along with the required developments to overcome existing limitations.

This document gives a summary of the main findings.
1.1 Overview

There is a lot of potential for the use of UAVs in the off-shore industry, from inspection, parts delivery, surveillance to health and safety issues. This document presents the main findings and the potential areas to be investigated for the future.

1.2 Main Findings

- Current use of the UAVs in offshore wind for inspection is similar in nature to those used in the oil and gas industry for structural inspection. However, the two environments are very different, oil platforms being more stable than off-shore wind tower and hence there are many difficulties in extending the current solution.

- There are currently no active applications for the delivery of parts or tools using UAV. However, this is a promising area of UAV application as about 10% of trips made to the towers may be affected by the lack of proper tools or parts.

- For UAV to be successful in the offshore wind area, there is a need to improve the following:
  - Improvement of human interface and control for VLOS;
  - Use of BVLOS technology because the farms are getting further and further;
  - Increase of battery life time or a distributed battery charging network strategy
  - Better navigation techniques especially in GPS deprived areas;
  - Automatic landing and take-off technologies on the tower;
  - Automatic loading and unloading to minimise human intervention;

- For AUV (Automatic Underwater vehicle), communication issues remain to be solved

- We see a potential for the use of a fleet of UAVs to perform complex and coordinated tasks such as carrying heavier loads, for coordination of multiple types of inspections using different types of cameras. The issues to be solved include algorithms for coordination communication of the UAVs and their behaviours, ability to adapt to dynamically changing environment, collision avoidance, etc.

The O&M sector for off-shore wind is relatively new where planning is fragmented and done in silos. There is a need for a more holistic integrated planning approach that uses UAVs as just another resource. This is a bigger research opportunity where all the different planning and execution areas and brought under one roof in an enterprise system.
2. Details of Findings

In this section, the summary of the research finding and recommendations for future research directions are presented. An extensive literature review was conducted to understand the current state of research for UAV, the main area of use, barriers and potential applications. In addition to UAVs, the literature search also covers AUV (Automated Underwater Vehicle) and ROV (Remotely Operated Vehicle). ROVs are tethered, i.e. have control cables attached to them. Interviews were also conducted with a dozen companies active in the area of UAVs. We first start by describing the main issues in tools and part delivery and then give the findings from the interviews and literature review.

2.1 Tools and Parts Delivery

As part of this study, we observed the current service operations for EON in Grimsby for the Humber Gateway off-shore wind farm. Each morning a set of service technicians leave to service the towers. These were grouped in two teams of 8 people and a CTV (Crew Transfer Vessel) assigned to each team for the day. Each technician has a set of tasks that he needs to perform on the towers and for each task he needed to ensure that he gets the proper parts and tools to complete his task. For security reasons no parts or tools are stored on the CTV and also no parts or tools can be left in the tower.

Planning of the tasks is done independently of tools availability in inventory and it may be the case that the tool is not available when the technician searches for it. For corrective maintenance tasks, it may be the case that the technician will only find out the part or tool that he needs once he is on the job. This will require a second trip to fix the issue. Based on interviews the current estimate is that as about 10 % of trips made to the towers may be affected by the lack of proper tools or parts.

AUV can help in delivering the missing parts and tools to allow a technician to complete his task. However, there are many issues to overcome for a successful implementation of UAVs in this context as parts and tools come in different shapes, weights and sizes. Another issue in transferring tools and parts from the vessels or land stations to the towers where needed. Flight length, navigation in GPS deprived environment, battery life, pay load, landing and take-off on towers and vessels are some of the issues that will need to be tackled in a robust integrated solution.

2.2 Interviews with Technology and Service Providers

A number of semi-structured interviews were conducted to collect the critical views and opinions of the experts in the field as to the readiness of UAVs. The questions were not limited to UAVs but also to AUVs and ROVs. Among the companies interviewed were A2SEA, Blueeye Robotics, EON, Quinetiq, Perceptual Robotics and SteelRock. Some of these companies are providers of services and others are users of the services. Of these companies only, EON had tested UAVs on off-shore towers for blade inspection and the exercise was not very successful according to them. The service provider had a lot of difficulties flying the UAVs from a ship deck resulting in a few being lost in sea. Sea sickness was another issue. Use of UAVs was abandoned for now by EON until a more mature solution is available. However, a recent news release by Orsted announced that they have successfully completed an automated inspection of their 80m wind turbine blade at the Burbo Bank Extension offshore wind farm off the coast of Liverpool.\(^1\)

\(^1\) https://orsted.co.uk/Media/Newsroom/News/2018/07/The-future-is-here-automated-drone-robots-inspect-massive-80m-wind-turbine-blades
Below are some of the important barriers and issues that have been mentioned during the interviews:

- Inabilities of UAVs to carry heavy payloads
- High possibility of collision
- Difficulties with Beyond Visual Line of Sight (BVLOS) accuracy for delivery
- Operation on moving platforms (vessels in rough sea or tower)
- Landing and take off facilities on current CTVs (Crew Transfer Vessel)
- Poor georeferencing technology in underwater operations for AUVs
- Difficulties in underwater data transmission for AUVs
- Ocean current and navigation of drones.

Some of the solutions that were suggested by interviewees include:

- Integration of high-resolution cameras with other sensors to increase the data feedback
- Application of auto-docking systems for drones
- Providing helidecks on CTV
- Use of crawler systems
- Provision of emergency medications by UAVs
- Use of subsea garages.

2.3 Literature Review

An extensive literature review was performed to better understand the state of the art in the application of Unmanned Vehicles (UV) in general to the O&M field for the off-shore wind sector. UVs include UAVs, AUVs, and many other types of semi or completely automated vehicles, details of which are given in appendix 1. The literature review can be categorized into two groups: Aerial and Underwater Vehicles. The search keywords used for Aerial vehicles were "UAV" or "drone" or "autonomous vehicles" AND "offshore" AND "oil" OR "gas" OR "wind" AND "turbine". Initially, 76 articles were collected for the period covering 2014-2017 which further filtered to 26 articles with innovative applications of drones based on their abstract.

UAVs have already been used in the offshore oil and gas industry (Gao, Yan and Wang, 2011) and have proven their applicability in data gathering. UAVs are also in use for inspections and small repairs in the onshore and offshore wind industry with an increasing rate. But we could not find any evidence of the use of UAV for parts and tools delivery. This means that this area of application is wide open.

The keywords for searching through articles in the underwater category were “Underwater Unmanned Vehicle”, “AUV” and “ROV” + “offshore maintenance”. Initially 53 articles were found that described approaches to improve the application of the AVs in the underwater environment. By filtering based on the abstract content, 20 papers were selected with practical potential approaches for future directions.
2.4 Current applications, barriers and potential future applications of UAVs

In addition to parts management, the following are some areas of the opportunities found in the literature for UAVs applications, along with suggested solutions and possible challenges to the solution development:

- The capability of turbine inspection without stopping the turbines can increase the run time of the turbines. Developing advanced machine visions, which are capable of synchronizing themselves with moving blades as well as a GPS-based navigation system with the ability to move from one tower to the next that is automatically planned, can create a huge opportunity in this area. However, these drones need to be equipped with precise distance measuring sensors to reduce the risk of collision with the blades during the operation.

- Continuous turbine inspection with the permanent presence of one or multiple drones on the tower has been suggested as an attractive approach that has been found both within the literature and also in the interviews that have been performed. Recent literature also suggests the use of crawling drones for this purpose. But, this solution also comes with its challenges. The drones must be facilitated with high technology equipment (e.g. HD cameras and NDT sensors) whilst consideration of the limited mounting capabilities, specifically in slippery conditions and on sharp edges of the turbines have to also be made simultaneously.

- Some tasks are too heavy for a single UAV to implement. Thus, there could be a need for a sophisticated costly drone with a high capability. However, a fleet of multiple small or simple low-cost drone can prove to be equally effective. Heavy payload deliveries can be an example of such a heavy task. Coordinating a team of collaborative UAVs with controlled payload distribution among them has been suggested in the literature to be a future research direction for such a purpose.

- Compared to homogenous teams of drones, heterogeneous teams are more complicated to deploy, control and plan, but the benefits are larger. For example, using UAVs for long flights between towers in harsh weather and long distances may not be feasible. But a USV (Unmanned Surface Vehicle) can be used to carry parts, tools and the UAV to the towers and add to the capabilities of the overall systems when used in collaboration (Collins et al., 2017).

2.4 Current applications, barriers and potential future applications of UUVs

A large part of an offshore wind farm is under the sea and thus, there is a requirement for underwater operations. However, these operations are proven to be challenging due to specific characteristics of the shallow waters (i.e. high ocean currents and low visibility). The following are some areas with potential opportunities from the literature to improve the application of UUVs:

- Human-robot interfaces: an effective human-robot interface can improve the performance of both drones and humans in terms of precision and time during an operation. Head Mounted Displays (HMD) for operators and moving cameras on drones, which are aligned with HMD, are a solution to increase the awareness and control of the situations for operators. Setting up Augmented Reality (AR) technology on the controller screens can also increase the perception of the operator from the situation of the drone and target position. Application of controllers that follow the operator’s body gestures instead of a traditional joystick, has also been suggested by the literature, in order to ease the interaction between operators and the drone.

- Utilization of data and signal transmission: the high absorption rate of the water poses data transmission difficulties. As a solution, some researches have applied underwater operation stations to reduce the transmission distance. Application of Ga-N based diodes to increase the bandwidth of data transmission is also being tested in some laboratories. Moreover, that use of submerged antennas that creates the opportunity of using radio frequency waves and underwater sensors and are connected to the main operation station by optic fibres, are among other suggested solutions.
• Navigation technologies: navigation of AVs under the water is not a straightforward task. Limited visibility and dynamic situation under the water, as well as high power currents, and difficulties with transmitting and receiving data to and from the drone can cause problems. The use of a navigator AUV alongside with operative or inspector AUVs, and the installation of underwater reference sensors are among the suggested solutions to this problem.

• Hybrid cooperation of ROVs and AUVs: Both ROVs and AUVs have some unique advantages. Application of ROVs can reduce the operating costs and improve the security. However, they need a mothership, an operating crew and a connecting cable. Application of AUVs can reduce the need for workforce up to 50% (Kermorgant and Scourzic, 2005). However, AUVs are not supported by human supervision and in complicated situations where the human intervention is necessary, they may show poor performance. Xiang et al., 2015, introduced a new class of unmanned vehicles named Hybrid Underwater Robotic Vehicle (HURV) which benefits from a range of features available to both types of the vehicles depending on the requirements of the mission combining the advantages of the AUVs and ROVs. There have been other developments in this area including Seaeye Sabertooth which is a HURV developed by the Saab Underwater Systems (Johansson et al., 2010). The vehicle can be operated in autonomous, operated-assisted and operator-manually modes. The transmission system is based on a download or upload station (can be an underwater station) where the vehicle is charged. This hybridisation of the different modes allows the vehicle to perform optimally with minimum manpower need.

2.6 Planning and Scheduling

UVs should be seen as an extra resource available for O&M activities and hence should be considered as such in an integrated planning system. Planning O&M activities is fairly complex given the environmental characteristics, limited resources and the existence of multiple teams, parties and stakeholders (often working in silos). Adding AVs into the system further increase the complexity. Therefore, in order to improve the resulting benefits within the operations, a new planning system that considers the necessities of AVs applications is needed. In particular, an effective mission plan for an AVs fleet will require these following factors:

• Task sequence rearrangement
• Selection target locations and optimal use of battery strategies
• Time restrictions and limitation-based maintenance planning schedules
• The precise path plan
• The configuration of the required equipment
• Integration within the context of a service trip
• Timely interaction with operators and Health & Safety concerns.

Therefore, there is a need for a new Decision Support Systems (DSSs) embedding AVs as a valuable asset in the O&M.
2.6 A holistic approach to enterprise planning for O&M

To fully utilize the application of AVs within O&M offshore wind farms, some initial prerequisites are needed. For instance, the installation of required infrastructures for deploying drones, as well as the promotion of a planning and scheduling system that can integrate the application of drones into O&M practices are essential to achieving an optimal use of AVs. Potential research avenues to develop these requirements can, therefore, be divided into short-term, medium-term and long-term actions.

• Short Term: To investigate integrated algorithms for dynamic maintenance planning and scheduling of resources with considerations for parts and storage locations through the use of AV automation and stochastic environment attributes.

• Medium term: Provision for the deployment of required infrastructures and technologies in the field for facilitating the use of AVs considering solutions to current issues (i.e. BVLOS payload delivery, docking operation, automatic loading and unloading and synchronization of fleets of AVs).

• Longer Term: To develop a holistic Enterprise Planning based approach for planning and scheduling of Operations & Maintenance activities with both vertical and horizontal integration, along with a command centre and control tower.

3. Conclusion

This report summarises the current application of UVs in offshore wind O&M and describes innovative opportunities to improve the use and benefits obtained from these vehicles. It also identifies the potential challenges to be solved for these innovations with a focus on tools and part delivery by UAVs. The findings are mainly based on interviews and a literature review. All the interviewees agree as to the potential benefits of using UAVs for tools and part delivery. But so far, we have found no evidence that it has ever been tested and therefore the research potential for this area is great. The following areas need to be tackled prior to applying the UAVs for tools and part delivery task:

• Provision for landing and take-off platforms on both the vessels and towers
• Automatic landing and take-off as well as loading and unloading mechanisms for UAVs
• Navigation and communication (data transfer and command receive) in BVLOS situations
• Payload capacity and battery life limitations
• Health and Safety concerns
• Integration of the UAVs in the detailed schedule and resource planning of the O&M by considering flexibility they add to the planning as well as their limitations and uncertainty they add to the process.

Moreover, there is an opportunity for looking at an integrated enterprise planning system in which the UVs is another resource. The goal of this system is to integrate all the activities within the wind farm, from planning to execution and integration with Backoffice applications such as warehousing, procurement, contracts management and accounting. The design of an optimal plan will then be done by the planning module by considering the priorities at the time, availability of resources and other issues such as the environment. Such a system is needed for the digitalisation of the industry and will help in lowering the energy cost.
References


