Industry Feedback: Opportunities for Autonomous Monitoring and Intervention in Marine Renewable Energy Arrays

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Abstract

Underwater monitoring and manipulation with autonomous underwater vehicles (AUVs) are active avenues of research in the Field Robotics Community. The purpose of this document is to briefly summarize some of the more promising research applications as well as provide information from four companies working in the area of marine renewable energy. This industry review demonstrates the potential benefit of autonomy in the marine renewable energy industry.

Industry Response

We contacted representatives at the following marine energy companies asking for feedback regarding the following items:

1. A short list of ROV-executed and diver-executed tasks, with estimated execution times per device, you foresee for array-scale installation, operation, and maintenance.
2. An estimate of how much time you believe could be saved by adding autonomy to these tasks.
3. The challenges you see in integrating autonomy into these tasks.

Companies contacted who design Wave Energy Converters (WECs) and Current Energy Converters (CECs):

1. M3 Wave LLC - (WEC designers)
2. Columbia Power - (WEC designers)
3. Ocean Renewable Power Company (ORPC) - (CEC designers)
4. Verdant Power - (CEC designers)

All four companies expressed interest in the use of autonomous vehicles for monitoring and intervention operations and responded with detailed e-mails. We have compiled and summarized the responses below. **Overall, we have identified multiple tasks where companies believe that a decrease in deployment time of 30% or more is possible with AUV operations (see detailed notes below). In cases where the ROV would not decrease the completion time, companies have stated that the elimination or reduction of divers would results in substantial cost savings.**

Deployed system examples:

- **M3 Wave's APEX:** sits stationary on the ocean floor and converts the pressure wave under ocean waves into electricity. M3 Wave LLC performed an open water deployment in Sept, 2014. They performed ROV imaging testing and sample collection in the months leading up to the project but shifted to divers during the actual deployment and operation for several reasons.
- **ORPC's tidal turbine system in Cobscook Bay, Maine**: Many of the activities ORPC performs subsea require a degree of flexibility to deal with unintended issues problems as they arise. They therefore depend on divers for subsea procedures right now. As they develop their technology and start to perform repeated operations they will be looking to remove the diver element from this work. Also, as they move to deeper water and more extreme environments, they believe that divers will be infeasible. Water conditions are 100 feet at MLLW, cold water, visibility of up to 10 feet at depth, slack water events from 20 to 40 minutes long. Given the depth, they are on the margins of requiring a decompression chamber, especially at high tide. They use hardhat divers for heavy construction work, and scuba divers for inspection and light construction activities. Insurance for these divers has been problematic.

ROV use cases identified:

- **Monitoring of sediment (M3 Wave):** Company's initial goal was to use the ROV for monitoring of sediment on and around the device during the multi-week test and take sediment samples. They chose a Deep Trekker 2 due to its small size and on-board lithium-ion battery, which made topside support equipment minimal. Their intent was to gain enough operational confidence to mount the ROV to PWCs that they were using for sonar mapping of the area. This would have allowed them to launch from shore and be on station in 6 minutes versus the 3-4 hours needed for a vessel to transit the Columbia Bar and motor to the site. Ultimately, the data quality and operational confidence was not adequate, and they added dive days to conduct the monitoring operations. By way of comparison, the ROV cost the same as ~2 dive days.
- **Wet connect and turning valves (M3 Wave):** Company identified these activities as irregular or infrequent deployment and O&M activities. In most of the cases of initial deployment as well as unplanned maintenance, they would consider divers initially. In those cases, uptime needs and flexibility requirements would offset any savings that might be gained from a complex AUV conducting a complex operation. Companies would pay to have divers standing by or even in the water anyway, monitoring the AUV in case of malfunction.
- **Biological and benthic monitoring (M3 Wave):** Company identified these activities as having a large potential benefit of AUV operation. This might include video, sediment sampling, 3D sonar imaging of sediment transport, EMF monitoring, acoustic monitoring, etc. The repeated, monotonous, lengthy aspects

of this process make it expensive to do with divers long term. This task was identified as one that might have a substantial benefit from ROV operations.

- **Preventative maintenance (M3 Wave):** This might include scraping or removal of bio-fouling, monitoring of mechanical and eletro-chemical wear indicators, system re-charge, video logging, etc.
- **Video inspection of installed power and data cables (ORPC):** Cables require regular video inspections from shore to the subsea central connection unit, approximately 3000 feet of length, with the cables alternatively buried and exposed. Finding the cables visually can be problematic. Navigating a GPS defined route would be more efficient. Time estimate 1 hour of inspection time. *Possible to reduce subsea time by ½ if they do not need to search for the cable.* This inspection is performed yearly, with an emphasis on benthic impacts.
- **Connecting TidGen Unit (ORPC):** Company has a subsea central connection unit into which cables from each TidGen would be fed, connected, and then transmitted on one cable to shore. To connect a TidGen unit requires (1) lifting a cover, (2) locating the connector box, (3) removing three wet mate dummy plugs (2 power, 1 data), (4) connecting the TidGen unit, (5) retrieving the dummy plugs, (6) replacing the lid. Time estimate for this is 40 minutes. Most of the diver time is spent in locating the proper elements and removing the dummy plugs, which can be difficult to remove. Creating a stab plate connector would reduce time and possibility of error. *The AUV approach would reduce time for this operation by approximately ½.*
- **Electrical connection of TidGen TGU to the array cable (ORPC):** They disconnect the power and data cables at the TidGen in order to retrieve the unit cleanly. These are wet mate connectors (again 2 power and 1 data). A full dive is required (40 minutes). *A stab plate arrangement will be required and again I would estimate a reduction in time by ½.*
- **Mechanical connections of TidGen to foundation (ORPC):** This consists of a series of 10 mechanical connections spread along the length of the turbine support frame. They have a cross-flow turbine, which is approximately 100 feet long. This work is performed by a team of 4 scuba divers, and each diver can work on 2 to 3 different connections in the course of a dive. This actually takes about 10 to 15 minutes and is quite efficient. This can be automated, but ORPC is not sure it can be made faster. The obvious way to reduce time is to reduce the number of connections. The unit is then connected to a rigging system from a surface crane and hoisted to the surface. Rigging time is approximately 15 to 20 minutes, and depends on how well the surface vessel can maintain station over the unit.
- **Inspection (turbine and ancillary equipment) and deployment, maintenance, retrieval (ancillary equipment) (Verdant Power):** Company states they would be interested in ROV/AUV operation if the cost and performance were competitive with their current alternatives. They believe there are certain operations where this may be true. However, they currently do not have enough information about the operational capabilities of these vehicles and how those capabilities impact cost, deployment, etc. Verdant Power sees value in the use of ROVs, and potentially autonomous ROVs,

specifically in the following areas: inspection (turbine and ancillary equipment) and deployment, maintenance, retrieval (ancillary equipment).

- **Periodic inspection of WEC hull and mooring with SCUBA diver(s) (Columbia Power)**
    - Estimated time: 2 divers 45 minutes each, 2 person support crew topside (deckhand and captain)
    - Frequency: once per quarter
    - Estimated time savings from autonomy: Inspection time assumed the same, but no divers and same support crew.
    - Total savings: 90 minutes per WEC per quarter
    - Challenges: Camera vision inspection with an AUV might have limitations as compared to a diver doing a hands on check.
- **Inspection and attachments during WEC ballast evolutions (Columbia Power)**
    - Estimated time: 2 divers 30 minutes each, 2 person support crew topside (deckhand and captain)
    - Frequency: once per 10 years
    - Estimated time savings from autonomy: Time assumed the same, but no divers and same support crew.
    - Total savings: 60 minutes per WEC per ten years
    - Challenges: Camera vision AUV inspection has limitations as compared to a diver doing a hands on inspections and attachments.
- **Inspection and attachments during WEC mooring installation (Columbia Power)**
    - Estimated time: 2 divers 30 minutes each, 2 person support crew topside (deckhand and captain)
    - Frequency: once per 10 years
    - Estimated time savings from autonomy: Inspection time assumed the same, but no divers and same support crew.
    - Total savings: 60 minutes per WEC per ten years
    - Challenges: Camera vision AUV inspection has limitations as compared to a diver doing a hands on inspections and attachments.
- **Unplanned intervention and inspection (Columbia Power)**
    - Estimated time: 2 divers 120 minutes each to address an unexpected failure identified during inspection, 2 person support crew topside (deckhand and captain)
    - Frequency: once per 5 years
    - Estimated time savings from autonomy: Inspection time assumed the same, but no divers and same support crew.
    - Total savings: 240 minutes per WEC per five years
    - Challenges: Repair event may not be addressable with AUV
- **Hull cleaning (Columbia Power)**
    - Estimated time: 4 divers 120 minutes each to clean critical surfaces
    - Frequency: 1 year
    - Estimated time savings from autonomy: Cleaning time by AUV may take longer and would require item 1 above to be implemented. Savings would be that a robot is doing perpetual cleaning on the array rather than divers and a support crew.
    - Total savings: 8 hours per WEC per year

- Challenges: implementing 1 above.

Main issues with ROV Ops:

- **Poor visibility:** This was in part due lighting and camera suitability (or lack thereof). Multiple companies are working on improvements to cameras and lighting.
- **Tether management:** Companies were attempting to operate in the near-shore area where station keeping of the launch vessel was critical, yet they could not use bow thrusters for lateral control due to risk of umbilical ingestion.
- **Navigation/situational awareness:** Companies had challenges finding/returning to the same spot for monitoring purposes since they lacked on-board compensated GPS or hi-res inertial nav.
- **Servicing requirements:** Close proximity from array to dock could allow AUV transit to the array without vessel support. A charging station and AUV accessible/exchangeable tool crib located within the array would allow for mission flexibility without bringing AUV back to dock.
- **Umbilical:** Umbilical entanglement is one of the biggest operational limiters. It even affects how and where they put marker buoys, since two cables within 100m of each other will often wrap around each other and intertwine. Also providing a benefit would be a "wireless" ROV even if it was not autonomous.

Companies see a substantial benefit to going autonomous for the following tasks:

- **Persistence/low cost mob/demob:** With an autonomous system, if it can recharge off an underwater junction box, would allow 24x7 monitoring**.** By avoiding the need to mobilize and demobilize deployment and recovery assets for every ROV/AUV mission, one can save significant amounts of O&M capital. One thing to keep in mind, the cost of an ROV deployment rig may not be much less than a diver platform when operations are in water shallow enough to facilitate conventional non-hardhat diving. A small boat, all day charter is required either way. But, if one could leave the robotic asset on the bottom for an extended period, it would save significantly in deployment vessel cost for long term operational monitoring of an array.
- **Surf entry:** As long as you have the power and the navigation capability, launching an ROV like you'd launch a PWC or Dory would potentially be feasible. For M3 Wave, shore launch puts them within 1 mile of the target site versus taking a vessel out of Astoria or Tongue Point, which is many miles.
- **Reducing risk to divers:** Divers are also error prone and their work is not easily inspected by QA/QC. Navigation and orientation for divers is difficult underwater as they are typically relying on site and can get easily disoriented. Down lines are often required for the divers and this leads to excessive lines in the water which could foul the unit.

Challenges identified for autonomous operation:

- **Station keeping:** In nearshore, relatively shallow environment (7-10 fathoms) surge is a factor. Companies have considered adding navigation aids to WECs with ROVs in mind - either "garages" for safe parking, optical indicators for navigation, metallic segments for magnetic adhesion and stabilization, etc. Companies think very soon you'll see more and more WEC designs evolve with DFRM (Design For Robotic Maintenance) in mind.
- **Situational awareness:** It's not enough to navigate to within view of an optical target. If the ROV is performing tasks like sediment sampling, the operator will need to specify where to take samples from (to within 1m or less resolution). That is a nontrivial sensor fusion activity. Some sample sites are away from the device(s), and putting extra sample site targets is not ideal due to permitting and reliability issues with anything left on the floor. Even small ROV's have a special sensor riser to get the compass sensor away from the ROV housing. Companies have trialed some small ROVs for inspection and found that the tether is the real drag on the system and makes the system uncontrollable.
- **Robustness.** Companies have seen some of the ROV/AUVs under development at universities and believe some are going to have a challenge in the real ocean environment. Imagine an AUV conducting a video transect down the length of the WEC, recording video of biofouling. Even the best navigation and station keeping thrusters in the world cannot predict when a big surge will come through and bang the robot against the steel side of the WEC. Need to be able to shake it off and keep motoring.
- **Fault recovery:** What happens when a failure happens? How does the 'bot know there's been a failure? Is the default mode "return to surface" where there is increased likelihood of the AUV becoming beached? Or do you drop anchor, pop a marker and phone home? When many ROVs have an issue, they are hauled back up using the umbilical (which is conveniently designed to be robust enough for that purpose). If a piece of algae wraps around a prop, you'll want to be able to identify and compensate to enable completion of the mission and/or safe abort. In many cases, companies have pulled up ROVs after an open water operation with some minor prop fouling that was enough to cause noticeable thrust yaw.
- **Highly energetic tidal flows:** In some coastal waters, there are approximately 60 minutes with water speeds below 1 m/s at each slack tide. AUV would need to perform in these types of environments. This brings into question the load capabilities of these AUVs (e.g., how much lift, torque, etc. can they generate and sustain).
- **Flexibility:** Divers are inherently more flexible in their work approach. Scuba divers are actually very efficient in transiting to the work site. They reach depth and are working within 5 minutes, and because they work in teams there are 2 pairs of hands at work in parallel. Hardhat divers are the least efficient for reasons that are worth examining: (1) These divers are encumbered by tethers, and the working window available is extremely limited by the drag on the tether and by

the entanglement possibilities of the tether. (2) One diver in the water limits the amount of work that can be done. (3) One diver in the water, having to move over a given distance limits the amount of productive time, as hard hat divers move slowly (tether management). (4) All of the divers and the ROVS are limited in the amount of working time that they have due to flow speeds.