Smart inspection ROV for use in challenging conditions

Smart Inspection ROV for Use in Challenging Conditions

Romano Capocci, Edin Omerdic, Gerard Dooly, Joseph Coleman, Daniel Toal

Mobile and Marine Robotics Research Centre (MMRRC), University of Limerick

romano.capocci@ul.ie

***Abstract*—This paper presents the design concept of developing a smart, inspection remotely operated vehicle (ROV) that is to be used in challenging conditions. The cost of installation and maintenance of marine renewable energy (MRE) devices must be reduced in order for the technologies to have further financial viability. Current inspection ROV technologies are unable to operate in the challenging conditions where these MRE devices are situated. To aid in the reduction of MRE installation and maintenance costs an ROV is being developed which will allow for remote inspection of these structures. The design process of the ROV is detailed. Computational fluid dynamics (CFD) analysis has been conducted to aid in making decisions on shape of ROV. The acquisition of equipment and testing of systems, such as the inertial navigation system (INS), is described. Results of initial tests are provided and the future work and testing is explained.**

Keywords—remotely operated vehicle; inspection ROV; marine renewable energy; inertial navigation system

I. INTRODUCTION

Ireland is in one of the best locations in the World in terms of MRE resources. Significant research and development is underway into the pursuit of a sustainable MRE industry sector, both in Ireland and on a European scale. Wave and tidal energy technologies can play a significant role in Europe's future energy systems; however this will be contingent on whether the levelised costs for generating electricity (LCOE) from MRE can become competitive with alternative technologies [1].

One of the key challenges in meeting LCOE targets will be the inspection, repair and maintenance (IRM) costs of MRE devices. In offshore operations, this is typically carried out using remotely operated vehicles (ROV) with expected costs for support vessel and ROV in the region of £100k+ / day. The overall maintenance cost of tidal energy installations is estimated to be £0.12 - £0.19m/MW/year and £0.09 - £0.22m/MW/year for wave energy installations [2]. However, due to strong tidal and wave regimes in which these devices will be located, IRM operational weather windows will be limited which can result in significant cost implications through MRE device downtime. In particular, for wave energy installations the window of opportunities for maintenance works will be limited. In fact, it is reported that wave heights of greater than 1 m are present off the coast of the west of Ireland for 98% of the time per year [3]. These limitations reduce maintenance opportunities and increase cost. If MRE devices are to become viable, leading to a sustainable MRE industry sector, IRM costs need to be addressed in the initial stages of MRE device development and offshore testing.

A smart inspection ROV is being developed in UL to aid in the reduction of these costs and details can be found in the remainder of the paper.

In Section II the current state of the art for ROV technologies is discussed. There is also a discussion on how the ROV being developed will offer more advancements than current technologies.

Section III discusses the design of the ROV. It details the required capabilities and how these are to be achieved. Various systems within the ROV are also described.

Section IV explains the work that has been carried out to date on the project. Details are explained of the various steps that have been run through to arrive at the current point in the research project.

In Section V the results that have been obtained are disclosed. These results include drag coefficients from computational fluid dynamics (CFD) analysis on various CAD models and test results of the commercial inertial navigation system (INS) that is being implemented in the ROV system.

Section VI lists the future work that is to be carried out over the coming two years in order to produce and quantify the performance of the vehicle.

II. BACKGROUND

Current ROV technologies are suited to deep-sea oil & gas operations and they can often display limitations in terms of operability in strong wave and tidal regimes. Typically pilot navigation is based on video feedback and the pilot can only react to a movement or situation after it has occurred. Furthermore, current technologies usually suffer from low thrust to weight ratio making them unsuited to challenging conditions, typical of MRE device locations.

Smart automated control algorithms coupled with low drag and high thrust to weight ratio can offer a significant improvement over current ROV technologies. This approach can reduce the time taken to complete tasks, allow for increased weather windows and increase vehicle control and safety. A low cost, smart ROV is being developed at the University of Limerick (UL), which will allow for inspection operations, however, it will lay a design path and platform from which a similar inspection and intervention ROV can be completed.

The ROV control system is based on OceanRINGS, a control system developed at UL and previously implemented on ROV LATIS [4], and will be developed further specifically for MRE operations. Figure I illustrates a sample of a user interface in the OceanRINGS software.

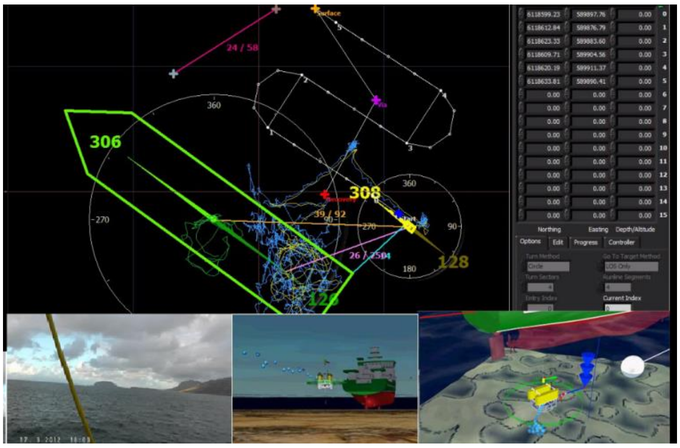


Figure I. ROV LATIS pilot control and visualisation screens.

The control architecture utilises a low cost, commercial inertial navigation system (INS) from Advance Navigation, which integrates surface GPS and a high accuracy depth sensor for accurate positioning underwater. This navigation information is integrated into the OceanRINGS control system. The system implements a control approach based on optimal control allocation to allow enhanced manoeuvrability [5], strengthening the ROV's capacity to properly address the underwater environment in terms of inspection and intervention. This approach demonstrates full six degree of freedom control and is equivalent to full 3-D dynamic positioning underwater.

Another issue with current ROV technologies is size. They can be large, making transportation, deployment and recovery a considerable operation, requiring expensive equipment, a large vessel and a large crew; this increases costs dramatically. Other ROVs can be small, which reduces transportation costs, but usually inhibits the ROVs capabilities. The ROV being developed is to be large enough to house the required equipment to allow it to operate in challenging conditions, but small enough to allow for it to be handled by a two-man team, reducing labour and transportation costs.

III. DESIGN OF ROV

Initially the expected conditions in which the ROV is to operate have been analysed. This has allowed for the equipment to be selected to allow the ROV to operate in said conditions. For cost effective power generation, tidal turbines must be situated in tidal currents with peak velocity at spring tide to be > 4 knots [6]. The ROV must have enough horizontal and lateral thrust to ensure that it can station keep in these strong currents. This can be accomplished by employing strong thrusters and careful design consideration to ensure that the thrust to weight ratio is kept to a maximum. For applications with wave energy converters (WEC) the ROV must be capable of operating with the strong heave conditions. To allow for this the ROV has been designed so that it will have at least two vertical thrusters. The ROV has been designed so that it will be modular. It will be capable of housing 8 thrusters. Depending on the application, the ROV can have the thrusters mounted in a way that suits. For example, if the ROV is required to interact with a WEC, 4 thrusters can be mounted in the vertical position, allowing for more control in the vertical plane. If the ROV is to operate in strong horizontal currents, the thrusters can be mounted so that there are 6 thrusters capable of keeping control of the ROV in the horizontal plane. Alternatively, the ROV can be mounted with the standard number of thrusters – 2 vertical and 4 horizontal, mounted in a vectored orientation. This vectored orientation allows for maximum control in a forward and lateral direction. The modularity of the vehicle also allows for auxiliary equipment to be mounted when required.

The physical dimensions and mass of the ROV are such that a two-man team can transport, deploy and retrieve the vehicle with ease. Additionally, the payload of the vehicle is expected to be in the order of 30 kg and sufficient enough that auxiliary equipment can be mounted to the vehicle without significantly impeding performance. The ROV will also act as a platform for another PhD project within the research group. This PhD is based on imaging using optical and sonar data which will aid in the navigation of ROVs in relation to MRE structures. The data from these sensors will be used to determine the orientation of the ROV in relation to a structure that is being inspected. For this project the hardware required is a camera and sonar system. This is to be mounted on the ROV. This system is to be added to the overall suite of tools that can be used to help decrease the costs of MRE installation and maintenance. The two pieces of equipment can be powered using PoE, which will be supplied by the Gbit network switch.

Maintaining the weight to a minimum not only ensures the thrust to weight ratio is increased; it also ensures that the requirement for a two-man team to transport, deploy and retrieve the vehicle is realised. Because of its portable size, the system will only require a small vessel for transportation. This will ensure that labour and vessel costs can be kept to a minimum.

To ensure that the ROV has sufficient power to allow the thrusters and communications equipment to operate, a custom power supply has been designed. This power system will send down up to 4.8 kW at 400 VDC. The high voltage allows for reduced current which, in turn, reduces the conductor size in the umbilical. The top-side power system has been designed so that it can be fed from a portable generator (two-man team) or from a ship's power supply. The power system will convert 230 VAC single phase to 400 VDC and transmit this down the umbilical.

Safety is an issue when working with electricity in water and high DC voltage. It can be dangerous for equipment and lethal for personnel. To provide protection to both equipment and personnel two different pieces of safety equipment will be employed:

- Line insulation monitor (LIM). This device monitors the resistance between the two conductors. If the resistance drops to below a certain threshold the LIM will either alert the operator or disconnect the supply. This device protects the personnel and the equipment in the system. This system is to be installed on the DC supply being sent down to the ROV.
- Residual current breaker with overload (RCBO). This device protects equipment from being overloaded, and personnel by disconnecting the power supply if there is a leakage to earth. This system will be installed for the AC power supply on the top-side.

The shape of the ROV has been designed so that it can house all the equipment required for it to function, but also to allow for minimal drag. The finalised shape of the ROV has been selected by using computer aided drawing (CAD) software and computational fluid dynamics (CFD) analysis on various shapes and layouts. The shape which resulted in the least drag has been selected. The results can be seen in the Results section.

An inertial navigation system (INS) has been acquired from Advanced Navigation. This INS inserts positioning data from a surface GPS antenna, pressure sensor and its own accelerometers, gyroscopes and magnetometers into a fusion algorithm which provides accurate navigation. 2-D tests have been undertaken and further, 3-D tests are to be carried out.

The control of the ROV is based on OceanRINGS, which is a control system that has been developed in the MMRRC centre in UL. This system has been developed over the past number of years. It has been tested on the ROV LATIS and shown to be highly accurate. The control system is to be modified to suit MRE operations specifically. There will also be changes made that will allow for control of the ROV with different orientation layouts of thrusters. This control can be changed in seconds by interacting with the user interface. The control system makes use of a top-side PC and a ROV-side mini PC, in constant, two-way, communication with each other.

The communications equipment has also been selected and obtained. The system will utilise Gigabit (Gbit) communications to ensure that all control data is promptly delivered.

To allow for the Gbit communications between top-side control and the ROV-side, a single mode fibre optic has been selected for use in the umbilical cable linking the two parts of the system. The ROV is rated for depths of up to 300 m so, in theory, a 300 m umbilical could be used.

The ROV is to be integrated with a pan, tilt, zoom (PTZ) camera, housed in a transparent dome. This camera operates in full colour HD and is powered with PoE. The camera will transmit the video feedback of targets from the ROV location. The targets subsea will be illuminated using two lights with high light output levels. These lights are still to be selected.

The communications equipment, camera, mini PC and navigation system is to be housed in a subsea aluminium pressure housing. The length and diameter of the cylindrical housing is to be minimised through optimum design and layout of the power system, INS and other equipment. The inner diameter of the housing is large enough to fit the outside diameter of the camera. The various connectors for power and communications, along with the connectors for external equipment such as thrusters, GPS antenna, lights and auxiliary sensors, are to be mounted on the rear end cap of the housing. The exposed end of the pressure sensor will also be housed on the cap.

The layout of equipment and, in particular, the power system on the ROV-side has been designed to optimise thermal conduction from the equipment to the outside face of the housing, where the seawater will dissipate the heat through forced convection. Aluminium heat conductor plates are to be attached to the bases of the power modules. A rack and pinion system is to be used. Once the skeleton, which the equipment is mounted onto, is inserted into the housing the pinion is rotated; this will cause linear movement of the rack, which will force the thermal plates, attached to the power modules, into contact with the inside surface of the pressure housing.

The buoyancy of the ROV is to be minutely positive; this is to allow for the following:

- Little thrust, and power, is required to keep the ROV in a vertically static position. This allows more extra power to be used to deal with horizontal movements.
- On seabed floors, where there is a possibility of kicking up sediment with extreme vertical thrust, the small thrust requirement allows for little sediment to be disrupted and thus visibility is not impaired.

- If power is cut or the tether is severed the ROV will eventually rise to the surface because of the positive buoyancy.

IV. Work to Date

A large database has been set up with a different section for each piece of required equipment. In each section various different manufacturers' products are collated and compared. This database has been used to make more informed decisions on what are the most suitable pieces of equipment for the ROV. Comparisons include cost, control, depth rating and several other characteristics. Table I shows comparison of various thruster models stored in database.

Table I. Comparison of various thrusters.

Thrusters						
Brand	***Model***	***Max. Thrust (kg)***	***Voltage (DC)***	***Max. Power (W)***	***Dim. (mm)***	***Weight in Air (kg)***
Engtek Manoeuvra Systems	SSE 100	19.5 →* 16.8 ←*	140 - 400	700	L 273 Nozzle Ø 206	3.86
Tecnadyne	300	8.2 → 3.6 ←	70 - 260	475	L 226 Nozzle Ø 111	1
Forum Sub Atlantic	SPE-75	26 →	300	1500	L 266 Nozzle Ø 177	3.3
Saab Seaeye	MCT 1	14 →	48	300	L 193 Nozzle Ø 221	4.3
VideoRay	M5	11 → 6 ←	48	650	L 130 Nozzle Ø 116	0.58

*→ denotes forward, ← denotes reverse

In parallel with the comparison of equipment, the physical size, shape and thruster layout has been decided upon. The size and shape is dictated by the equipment required and the fact that the ROV is to operate in challenging conditions. To allow for operation in these conditions, multiple strong thrusters are required, coupled with a shape that provides the least drag possible. A number of layouts and shapes were created using a SolidWorks software package. These models have then been subjected to computational fluid dynamics (CFD) analysis. Figure II illustrates the experimental flow trajectories of one of the ROV shapes in a seawater flow of 2 knots. This analysis generated estimate drag coefficients for the various shapes which aided in the selection of the final shape.

The commercial INS has been tested in surface mode i.e. in a 2-D environment with and without GPS aiding. For the test the INS was connected to a laptop, having the Spatial Manager software from Advanced Navigation installed on it. The INS was connected to laptop via a USB to Serial cable, providing power and data link of 115200 bauds. The laptop received power from an inverter which was connected to a 12 VDC power outlet in a car. The test equipment can be seen in Figure III.

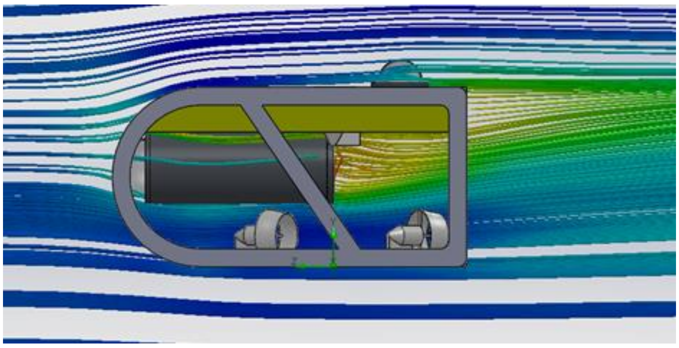


Figure II. Flow trajectories in CFD analysis.

Figure III. Test equipment for INS testing.

In Figure III it can be seen that the INS system and GPS antenna have been inserted into the foam enclosure, providing protection from mechanical impacts and vibrations. After a 2-D calibration, the initial test involved driving a car around a pre-defined route with the GPS aiding turned on. The next step was to turn off the GPS and then drive the car over the same route. The results were positive and can be seen in Section V.

A test bed has been set up in a dry lab facility at UL where integration testing of the various ROV components is underway. Additional sensors and components such as optical cameras, INS system, media converters and switches have been chosen and integrated, and testing is expected to be completed in the coming months. The test bed can be seen in Figure IV. For the testing of the equipment on the test bed, lab power supplies have been used. Using this test bed allows for the engineers to ascertain that all equipment is communicating with each other and that full integration is obtained.

Figure IV. Test bed for equipment integration.

A prototype frame has been constructed from polypropylene. This frame is to be used as a platform for initial layout design and early subsea navigation testing.

Table II. Power requirements for ROV equipment.

Power Supplies				
Equipment	***ROV-Side Power Module Voltage (V)***	***Equipment Required Voltage (V)***	***Equipment Rated Power (W)***	***Working Power (W)***
USB/serial adapter	12	5*	5	5
Fibre to Ethernet Converter	12	5*	5.4	5
Mini PC	12	19*	65	55
Relay	12	12	12	11
IMU	12	12	2	2
PTZ Camera	12	12	15	15
Camera for other PhD	12	12	2.5	2.5
Pressure Sensor	12	12	1	1
Lights (2)	24	24	120	120
DVL	24	24	80	5
Sonar	24	24	15	13
Sidescan	24	24	12	11
Gb Ethernet switch	48	48	60	50
Thrusters	48	48	3534	3534
Total			3928.9	3829.5

Note *: some ROV equipment will need dedicated DC-DC power converters to convert from the available voltages of 12, 24 & 48 VDC.

After the selection process of the required equipment has been completed, the required power supplies and voltages were then collated. This has been carried out to aid in the process of power supply selection. The equipment has been grouped into three sections, relating to required voltages – 12, 24 and 48 VDC. The three groupings allow for less power modules to be used, resulting in savings of cost, weight and size. The equipment with the largest power draw is the thrusters, which are VideoRay M5. These thrusters will have a voltage rating of 48 VDC and power draw of 570 W at maximum continuous thrust. Software module to distribute available power among thrusters has been developed, allowing 6 thrusters running at 100% and 2 running at 10%. This equates to 3,534 W required for the thrusters alone. The power requirements for other components are given in Table II.

The power supplies have been selected using the requirements from Table II. The three voltages and their power requirements have been further broken down so that specific power modules could be selected for each voltage. The power requirements for each voltage can be seen in Table III.

Table III: Power requirements for different voltages.

Voltage (V)	**Required Power (W)**
12	96.5
24	149
48	3584

Based on the above information, and after considerable calculations, the power system has been selected. On the Top-side, the 230 VAC power is to be delivered into two power packs. These power packs are to be connected in series, one providing +200 VDC and the other providing -200 VDC, giving a 400 VDC supply of 4.8 kW. On the ROV-side, the 12 VDC components are to be supplied by a power module that can supply 150 W with a minimum efficiency of 85%, giving 127.5 W. The 24 VDC components are to be supplied by a power module that can supply 300 W with a minimum efficiency of 86.5%, giving 259.5 W. As the 48 VDC components require a large power supply several power modules are to be connected in parallel. The modules being used can supply up to 600 W so 7 are to be connected in parallel, providing 4200 W. The minimum efficiency of these modules are 87%, which provides 3654 W.

Thermal dissipation is an issue when dealing with electronic components in enclosed spaces. The efficiencies in the power modules can be greatly reduced if heat is not dissipated sufficiently. Calculations have been carried out to aid in the selection of suitable thermal conductors and thermal sinks. A solution has been designed where a rack and pinion gearing device will allow the thermal conductors, which are to be attached to the power modules, to be pressed against the inside wall of the aluminium pressure housing, allowing for thermal conductivity between the power modules and the pressure housing. The initial design of the thermal dissipation system can be seen in Figure V.

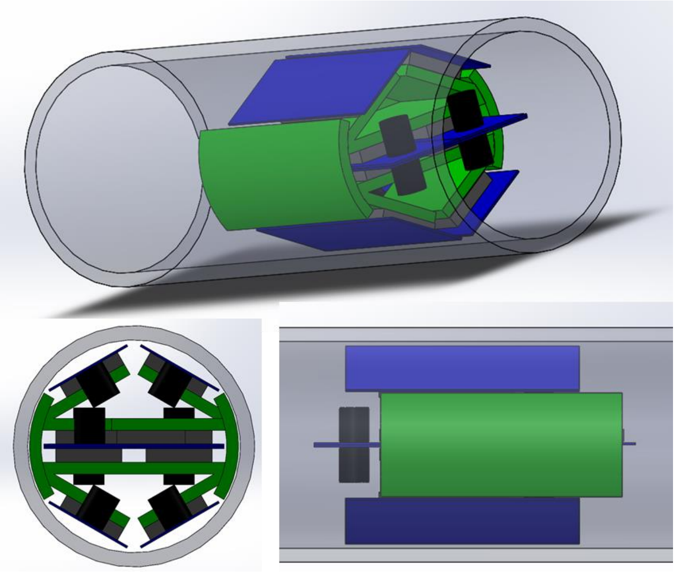


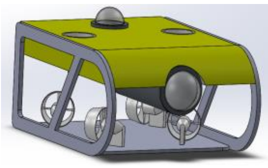
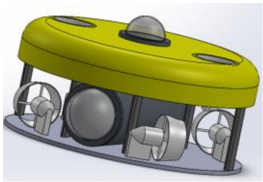
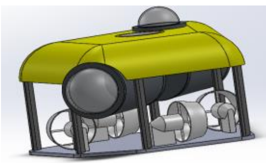
Figure V. Thermal transfer from power modules.

In Figure V the power modules are depicted in black, grey and blue, the thermal conductors are depicted in green. When the components are inserted into the bottle the rack and pinion gear is retracted. Once inside, the pinion is rotated and the rack extends, pressing the thermal conductors against the inside surface of the housing. When the heat is conducted to the outside surface of the housing, seawater will act as a forced convector and dissipate the heat away.

V. Results

Using CFD analysis on various ROV shapes and layouts results have been calculated for the shape with the minimum drag coefficient. The results of some of the ROV shapes can be viewed in Table IV.

Table IV. CFD drag results on various ROV shapes.

ROV Shape	Drag on Vehicle
	2.93 kg
	3.86 kg
	3.25 kg

` The results obtained in Table IV have been calculated using the fluid medium as seawater at a velocity of 3 knots. As can be viewed, the shape that generated the least drag is the box shaped ROV with a round fillet on the front face of the buoyancy block.

The next set of results was attained during the 2-D test of the INS system. The INS, located in a car, was driven around a pre-determined route with the GPS function switched on. The system displayed extremely accurate results. The GPS function was then turned off, allowing for the INS's gyros, accelerometers and magnetometers to determine the route. The result is positive and can be seen in Figure VI.

Figure VI. INS test results.

The route, as can be viewed in Figure VI, is a large rectangle located in a disused carpark.

VI. Future Work

Equipment has been procured which will allow the INS to be tested in an underwater, 3-D environment. A temporary housing, rated to 30 m, will house the INS, pressure sensor, mini PC and other communication conversion adapters, is to be mounted on to the polypropylene frame. The equipment in the housing is to be connected to the surface via an umbilical with power conductors and conductors for data throughput. The mini PC in the housing will receive outputs from the INS and pressure sensor, and carry out calculations to determine the position of the housing and frame. On the surface a PC receives the positioning data and displays it on to a monitor. The INS and frame will then be transported to various coordinates underwater that have a definite positional coordinate. This test will determine the INS's accuracy in an underwater, 3-D environment.

The pressure housing is to be designed so that all the ROV internal equipment can be mounted within it.

When the power system is obtained it will be tested in the lab to determine its actual efficiency when equipment is connected to it. The rack and pinion system, along with the frame to mount the power modules and equipment, is then to be constructed.

The thrusters, which are currently on order, are to be connected to the Ocean Rings software and tested in the dry lab. Thereafter the thrusters will be mounted on the ROV frame so that wet testing can commence

After all dry lab testing is complete, the equipment is to be mounted on the frame and the ROV will be tested and quantified through a series of in-situ tests at Limerick Dock and in the flow of the Shannon Estuary. Furthermore, final testing is expected to be carried out at sea from a survey vessel.

ACKNOWLEDGEMENTS

This publication has arisen from research supported by Science Foundation Ireland under the MaREI research programme [Grant No. 12/RC/2302]. The MaREI project is also supported by the following industrial partners: IDS Monitoring, Shannon Foynes Port Company, Teledyne BlueView and the Commissioners of Irish Lights.

REFERENCES

[1] SI Ocean, "Ocean energy: cost of energy and cost reduction opportunities," May 2013. [Online]. Available: http://si-ocean.eu/en/upload/docs/WP3/CoE%20report%203_2%20final.pdf. [Accessed 10 July 2015].

[2] DECC, "Review of the generation costs anddeployment potential of renewable electricity technologies in the UK," Ove Arup & Partners Ltd, London, 2011.

[3] M. O'Connor, T. Lewis and G. Dalton, "Weather window analysis of Irish west coast wave data with relevance to operations & maintenance of marine renewables," *Renewable Energy,* vol. 52, pp. 57-66, 2012.

[4] D. Toal, E. Omerdic and G. Dooly, "Precision navigation sensors facilitate full auto pilot control of Smart ROV for ocean energy applications," in *IEEE Sensors Conference*, Limerick, 2011.

[5] O.-E. Fjellstad and T. I. Fossen, "Position and attitude tracking of AUV's: a quaternion feedback approach," *Oceanic Engineering,* vol. 19, pp. 512-518, 1994.

[6] J. Ali, J. Khan, S. M. Khalid and N. Mehmood, "Harnessing marine energy by horizontal axis marine turbines," in *12th International Bhurban Conference,* Islamabad, 2015.