Control Architecture of a prototype for the real-time validation of emersion and immersion maneuvers of underwater devices for energy harnessing

M.P. Portilla[1], M. Espín[1], J.A. Somolinos[1], A. López[1] and R. Morales[2]

[1]GIT-ERM. ETS Ingenieros Navales. Universidad Politécnica de Madrid
Arco de la Victoria 4, 28040 Madrid (Spain)
{marinap.portilla; montserrat.espin; joseandres.somolinos; amable.lopez}@upm.es

[2]ETS Ingenieros Industriales. Universidad de Castilla-La Mancha
Campus Universitario s/n 02071 Albacete (Spain)
rafael.morales@uclm.es

Abstract. The exploitation of renewable marine energy sources requires devices which have been proven to be economically competitive with regard to other traditional energy sources. One of the current study aims is to reduce maintenance costs by successively automating more tasks. Since building real scale prototypes is too expensive and impractical, it is necessary to design and build laboratory prototypes in order to validate both the dynamic model and the control algorithms for the automatic emersion (depth to the sea surface) and immersion (from the sea surface to the depth of operation) maneuvers of hydrokinetic devices with which to harness renewable energies.
This paper presents the instrumentation and control architecture of a reduced scale prototype that was conceived for experimentation in a calm water basin of up to 2 m in depth. It is based on a new modular actuator set together with a depth and a 3D-attitude sensor system connected by means of a NI-Crio embedded computer. The prototype of the proposed architecture allows us to validate different control systems by only re-programming the respective control algorithms.

Keywords: Control Architecture, Experimental Prototype, Renewable Marine Energies

1 INTRODUCTION

The growing of interest in marine renewable energies has led to the appearance of multiple devices with which to exploit different energy sources from the sea. Some of these devices are being commercially exploited while others are already being researched. The three main energy resources from the sea are those harnessed from wind power, from waves and from marine and ocean currents [1]-[6].

It is expected that the development of devices with which to harness ocean currents will be similar to the evolution of oil and gas platforms for ever deeper waters (See [7] a.e.). A first classification of devices that use marine currents is related to the mooring system or anchoring to the seabed: the so-called first generation requires depths of less than 40 m and a structure or civil works for installation. Examples of the first generation devices can be seen in [8]-[9].

The second generation of devices, meanwhile, considers those floating devices that are moored to the seabed by means of wires, ropes and buoys. Examples of the second generation devices can be seen in [9]-[10].

In the case of all of these devices it is necessary to consider the operations used to take the device out of the sea to the surface and vice-versa in order to perform maintenance tasks. There are three types of devices based on this criterion:

- Those that use a servo actuated crabbing based system to move the main generation unit from the support structure.
- Those that use floating cranes for elevation and placement.
- Those that use a ballast management system to generate vertical forces, thus enabling the device's emersion and immersion movements to be controlled.

It is well known that the automation task results in a reduction in costs, and automating the emersion and immersion maneuvers for underwater devices that have been conceived to harness marine renewable energies therefore allows the time and economical costs involve in maintenance tasks to be reduced.

Furthermore, the device installation procedures at sea consist of several stages, starting from the concept formulation and the laboratory scale prototype, and culminating in full-scale commercial devices (See the Southampton Protocol at [11] a.e.).

In this work, we present the instrumentation and control architecture for a laboratory prototype that allows us to study the behavior of a device for the exploitation of ocean currents presented in [12].

This family of devices (See [12]) consists of a central nacelle or pod in which the Power Take Off (PTO) is responsible for converting energy from ocean currents into electricity. It is of an approximately cylindrical shape. Three arms that emerge radially from the central cylinder, each of which have a symmetrical disposition of 120º, support three torpedoes that are aligned with the pod cylinder. These torpedoes have two main functions: i) the alignment of the device with the flow when it is in operation, and ii) to serve as ballast tanks in order to perform emersion and immersion maneuvers. This kind of devices can be installed in deep waters (over 40 m), thus avoiding the high costs of civil works for installation, such as special ships with cranes for maintenance, requires only a small inexpensive tugboat.

Figures 1 and 2 show the general appearance of the generator along with its two main modes of operation: a) submerged, extracting energy and arranged vertically; b) floating on the surface, in the maintenance position and arranged in a landscape mode. See details in [10], [12].
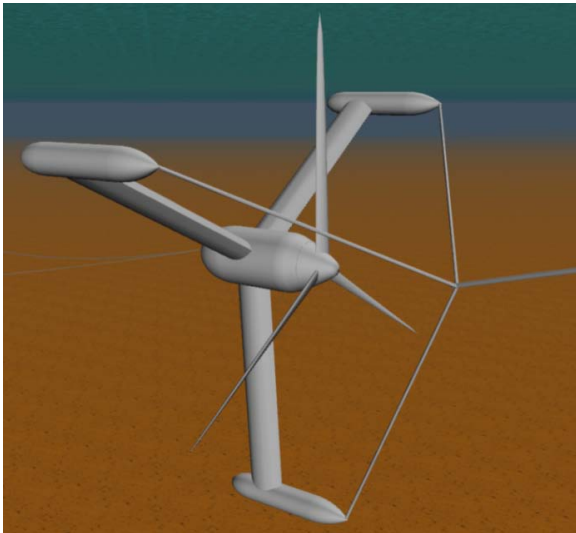

Fig. 1. General view of one of the proposed devices. Operation mode
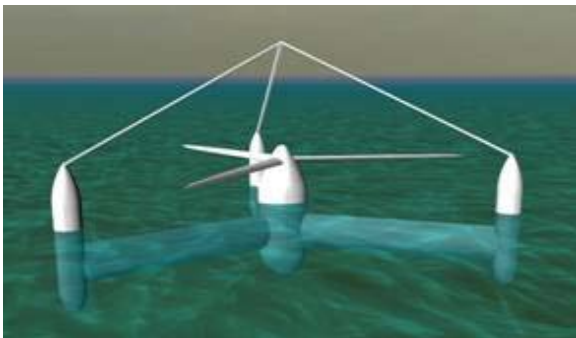

Fig. 2. General view of one of the proposed devices. Maintenance mode

Since the use of a real scale prototype is too expensive and impractical for research purposes, the small scale prototype that is presented in this research was built as a laboratory experimental prototype to be tested in a calm water basin. It retains the original layout of the device with three torpedoes arranged at 120º, and requires a system fully on board of actuators, sensors and computer equipment to control both its depth and its orientation.

2 PROTOTYPE DESCRIPTION

This section presents a brief description of the proposed laboratory prototype. Its initial specifications were:

- Its dimensions had to be appropriate for the calm water basin located at the ETS I Navales at the Universidad Politécnica de Madrid which is 100 m long, 3 m wide and 2 m deep.
- It would serve as a basis for the experimental study and validation of the dynamics of submerged and semi-submerged bodies with different shapes, and therefore had to be reconfigurable.
- It would serve as a basis for experimentation with various control algorithms for depth and orientation, and therefore had to be easily programmed.
- It had to be instrumented in order to measure and record a great number of variables for control and further analysis purposes.
- It had to have a modular drive system with easy assembly / disassembly, and additionally had to be interchangeable, expandable and/or changeable.
- It had to be possible to ship the computer onboard owing to the need to reduce the presence of cables outside, which would alter the dynamics of the whole prototype.
- A highly efficient use of human resources for the design and development was also desired.

The prototype shown in Figure 3, which is considered to be a central nacelle from a first generation tidal energy converter (TEC), was used to study dynamic behaviors during emersion and immersion maneuvers with both an open and a closed loop. The dynamic models and various control schemes obtained were also successfully experimentally validated. The cylinder of this one degree of freedom (DoF) (of motion) prototype is 608 mm in length and 200 mm in diameter.
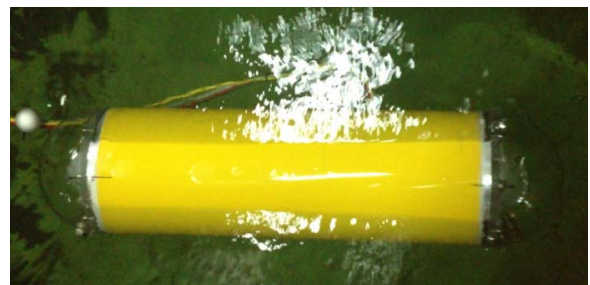

Fig. 3. One degree of freedom prototype during an open loop emersion maneuver

With regard to this one DoF prototype, Figure 4(a) shows the CAD appearance of three empty torpedoes with the binding system, while Figure 4(b) depicts the final appearance of the proposed 3 DoF prototype that was built by the author's team and technical staff.

The actuator assemblies may be seen at the ends of each of the three torpedoes in Figure 4(b). The cylinder located in the lower left-hand side of Figure 4(b) corresponds to that depicted in Figure 3. As both Figures 3 and 4(b) show, transparent hemispheres were added to both ends of each of the torpedoes. The main utility of these hemispheres is to reduce the effects of nonlinearities such as turbulence and vortex generation around the flat faces of each cylinder. This three DoF prototype can be easily assembled / disassembled as three individual torpedoes for easy transport or handling.
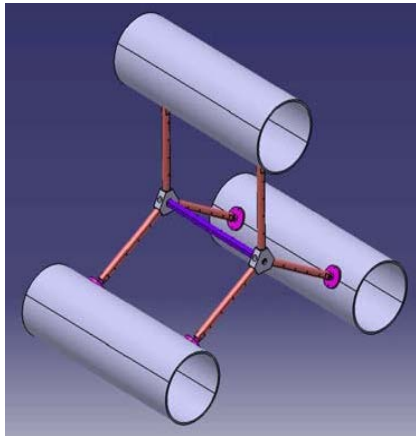
Fig. 4. Reconfigurable reduced scale 3 DoF prototype

a)   CAD view of torpedoes and binding system   b)   Final aspect of the prototype at the laboratory

3 CONTROL ARCHITECTURE

This section provides a brief presentation of the proposed instrumentation and control architecture. Two actuator sets are coupled to both sides of each of the cylinders in order to handle the buoyancy of the submerged platform by changing the volume of four small controlled pistons on each one.

Each of the actuator's servo system sets is composed of a Maxon RE40 40 mm 150 W DC motor, a reduction gear and a trapezoidal spindle/nut, which converts rotational motion from the gear shaft into the linear displacement of the pistons.

The position of the four pistons is closed loop controlled with PID controllers using a Maxon EPOS [13] and an embedded optical encoder coupled to the motor shaft.
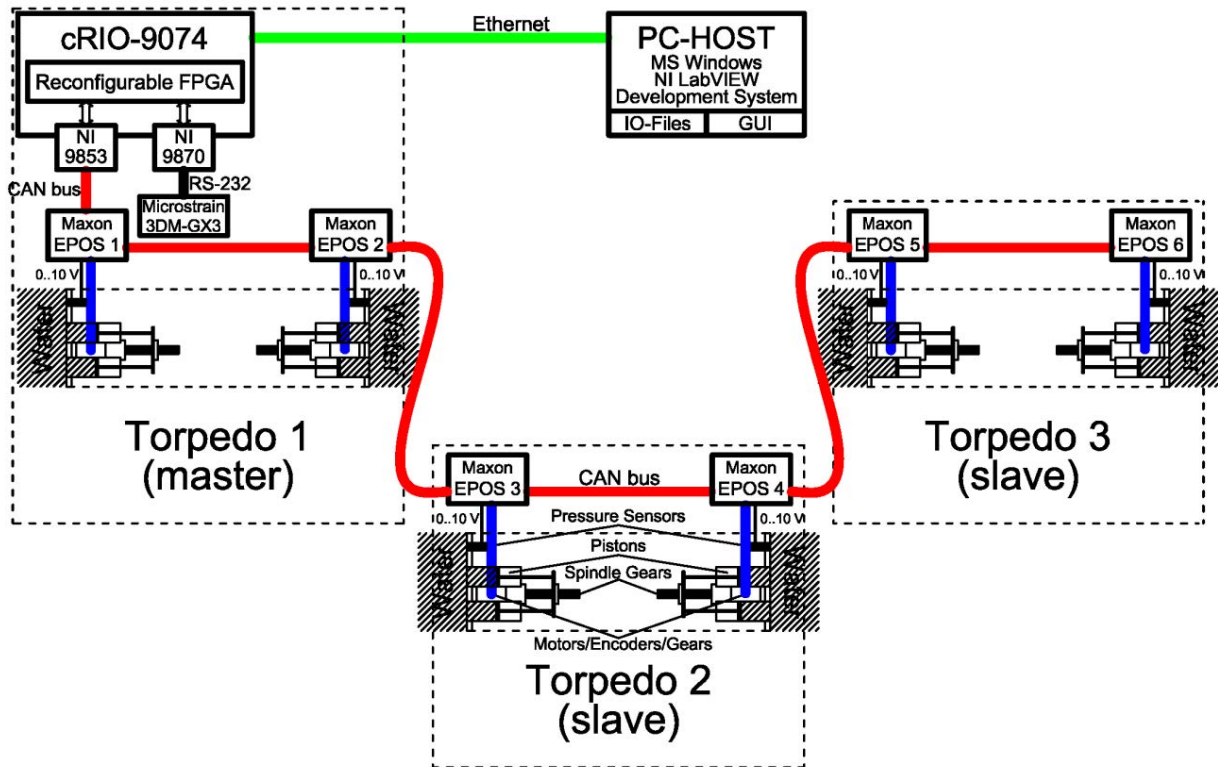

Fig. 5. Proposed Instrumentation and Control Architecture

One DPF absolute pressure sensor E13-VF is placed on each of both the flat faces of each cylinder. These are used as primary sensors to measure depth z after calibration and after discounting atmospheric pressure [14]. Each sensor provides an analog signal output with a small rising time which is connected to the analog IO unit of the respective Maxon EPOS2 by means of a three wire cable that includes a power source for the sensor and a differential voltage signal transmission.

Finally, in order to provide full range attitude measurement and control, a Microstrain 3DM-GX3-25 [15] full range triaxial inclinometer is placed on an inner orthogonal basis which is aligned with the main axis of the master (first) cylinder (the same used for the one DoF prototype).

A NI cRIO-9074 [16] integrated 400 MHz Real-Time Controller provided with a 2Mb Gate FPGA and an Ethernet port is used as an embedded control computer and is also placed inside the master (first) cylinder. Two cRIO modules are used for I/O purposes: A NI-9853 module is used as a CANbus interface to connect six Maxon EPOS, while a NI-9870 module is used as an RS-232 interface to connect the triaxial inclinometer.

A Personal Computer provided with Microsoft Windows and a NI Labview Development Environment (Real-Time, FPGA and optimization, among other libraries, are mentioned) is used as both the host and the development unit. It is connected to the cRIO computer via an ethernet connection. The Graphical User Inteface (GUI) and I/O files are handled by the user via this computer. Programming is carried out with LabVIEW together with the low level drivers provided by the manufacturers. Figure 5 shows a general scheme of the proposed hardware architecture. The umbilical connection from the cylinder to the outside consists of only an ethernet wire and a DC power supply line.

4 CONCLUSIONS

The instrumentation and control architecture of a prototype designed and built for the experimental validation of both dynamic models and control algorithms with which to maneuver the emersion and immersion of submerged devices used to harness hydrokinetic marine energies has been described.

The prototype described has been conceived in a modular manner; it can be configured with different shapes, it is extensible and it can be used as a laboratory prototype in which different control algorithms can be implemented. Its design was based on the size of the calm water basin located at the ETS de Ingenieros Navales at the Universidad Politécnica de Madrid, all its components are considered to be embedded, it requires a minimal presence of cables, and the proposed concept of modular actuator's system sets together with a sensor for depth measurements, thus allowing it to be easily assembled and disassembled. If a three-dimensional integrated inclinometer is placed onboard, it is possible to control both depth and attitude.

The proposed instrumentation and control architecture is based on a host-PC in a Windows environment and a NI-RIO embedded computer which is responsible for acquiring measurements from sensors, processing control algorithms and obtaining the control signals to the actuators of the prototype. This prototype is the basis used to validate both simple dynamic models and different real-time algorithms for depth and/or orientation control purposes.

REFERENCES

[1] A. Brito, J.L. Villate. Editors (2014), "Annual report. Implementing agreement on ocean energy systems-2013", *The executive committee of ocean energy systems*.

[2] J. Hardisty (2009), "The analysis of tidal stream power", Wiley.

[3] J. King, T. Tryfonas (2009), "Tidal stream power technology-State of the art", *IEEE OCEANS'09 Conference*, Bremen, Germany, ISBN: 978-1-4244-2523.

[4] C.M. Johnstone, D. Pratt, J.A. Clarke, A.D., (2013), "A techno-economic analysis of tidal energy technology", *Renewable Energy*, vol. 49, pp. 101-106.

[5] A.S. Bahaj, (2011),"Generating electricity from the oceans". *Renewable and Sustainable Energy Reviews*, vol. 15, pp. 3399-3416.

[6] M.S. Güney and K. Kaygusuz (2012), "Hydrokinetic energy conversion systems: A technology status review", *Renewable and Sustainable Energy Reviews*, vol. 14, pp. 2996-3004.

[7] Mustang Engineering. Offshore Magazine (2014) "Deepwater solutions & records for concept selection". In http://www.offshore-mag.com/maps-posters.html

[8] A. López, J.A.Somolinos, L.R.Núñez, (2014), "Energetic modeling of primary converters for marine renewable energies". *RIAI Revista iberoamericana de automatica e informática industrial*, vol. 11, no. 2, pp. 224-235

[9] IEC-TC214 (2011), "Tecnhical specification: Marine energy. Wave, tidal and other water current converters. Part 1: Terminology", IEC/TS 62600-1 *Ed. International Electrotechnic Commision*. Ginebra, Switzerland.

[10] A. López, J.A. Somolinos, L.R. Núñez, J. Valle, (2011) "Dynamic behavior of a second generation hydrokinetic converter" *In Proceedings of the IEEE International Conference on Oceanic Engineering*. OCEANS 2011. Santander (Spain).

[11] Tidal-current Energy Device Development and Evaluation Protocol URN 08/1317. Department of energy and climate change, University of Southampton, 2008.

[12] Spanish Patent and Trademark Office. (2008): "Patent number concession nº P200700987" UPM. OEPM. Madrid.

[13] http://www.maxonmotor.es/maxon/view/content/EPOS-Detailsite. Consulted April 30, 2015

[14] http://www.dpfsensors.es/presion.htm. Consulted April 30, 2015

[15] http://www.microstrain.com/inertial/3DM-GX3-25. Consulted April 30, 2015.

[16] http://sine.ni.com/nips/cds/view/p/lang/es/nid/203964. Consulted April 30, 2015