A competition for WEC control systems

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***Abstract*—This paper outlines a proposed open competition which will compare energy-maximising controllers for wave energy converters (WECs), both in simulation, and in real time, using a scale device in a tank test situation. To date, a wide variety of WEC control algorithms have been proposed, but have been difficult to compare due to differences in the simulation/scale models they are evaluated on, the range of incident sea states employed, and the reliance to a greater or lesser extent on wave or excitation force forecasts. In addition, most WEC control algorithms have been evaluated only in simulation, which masks the real-time computational capability, as well as the degree to which the model-based controllers are robust to WEC modelling errors, since the controllers are predominantly evaluated with a WEC simulation model identical to that upon which the controller is based.**

This paper describes the format of a proposed WEC control competition, detailing the scale target device, the open-source WEC-Sim simulation platform, along with likely performance metrics and range of sea states under which the assessment will be performed. The paper serves the purpose both as an announcement of the competition and indicates the nominal schedule, as well as soliciting feedback at this stage of the process.

***Index Terms*—Wave energy, control, competition, WEC-Sim, Wavestar**

I. Introduction

Energy in ocean waves is distributed across a wide range of frequencies, with a challenge to optimise the loading of a WEC to maximise power capture across a range of sea states that a wave energy installation may be subject to. When using simple resistive damping control, even a well-designed device will fail to capture much of the energy in ocean waves. As such, a large number of studies have begun to investigate advanced control design and implementation for WECs; these studies have generally shown very attractive results for increased energy absorption as well as performance factors such as decreased loads [1]–[3] and represent a key path towards lowering the levelized cost of energy (LCOE) for WECs [4].

While there are a significant number of studies which evaluate particular devices under particular wave excitation conditions, few studies exist (with the notable exceptions of, for example, [1] and [3]) which compare a number of control strategies on one (or a set of) standard device(s), with consistent wave excitation applied in each case, to level the playing field. However, controller evaluations are usually carried out in simulation, where the simulation model is often identical to that used to build the model-based controller. In such a situation, any controller sensitivities due to modelling inaccuracies are masked in the evaluation. In addition, due to the non-causal nature of the generic impedance-matching control problem [5], future information (available in simulation environments) [6] is often assumed for controller. While there are ways of estimating such future information [7], the effects of the estimation errors are not always considered [8]. Finally, the real-time computational requirements of WEC controllers are not always clear from simulation studies.

Despite the comparative simulation results available [3], there is also a desire to compare a variety of WEC control strategies under real, or at least wave tank, implementation scenarios (see, for example, [9]), so that all real effects are encountered, such as nonlinear hydrodynamic and PTO effects, realistic measurement assumptions, including the presence of measurement noise and bias, and real time computational requirements. Ironically, the challenge for WEC controllers for small scale WECs can be greater, due to the exaggerated role of friction, and the shorter sampling rate requirements associated with faster dynamics, but these issues are, at least, consistent for each of any compared control strategies.

In many technical areas, open competitions have been held to provide comparative evaluations of technical solutions and to provide some level of consensus as to the way forward, for example in time series modelling [10] and wind turbine fault diagnosis [11]. Some control-specific competitions have focussed on wastewater treatment systems [12] and hybrid electric vehicles [13]. In recent years, a number of open competitions have also been held in the wave energy area, with the most prominent being the US Department of Energy Wave Energy Prize [14], which focussed on the power production capabilities of novel wave energy device prototypes, while a specialist competition on hydrodynamic modelling has also been held [15]. A competition to compare WEC simulation codes is documented in [16].

The objective of the currently proposed competition, which

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will consist of a standard WEC prototype platform, is to compare the energy capture performance of various WEC control strategies evaluated, in the first instance in simulation and then, for shortlisted entrants, on the prototype device in a wave tank environment. In order to provide a consistent simulation environment for both competitors and evaluators, the WEC-Sim simulation environment [17] will be employed. For wave tank testing, the real-time control algorithms will be implemented using the Matlab/Simulink xPC environment.

The remainder of the paper is laid out as follows: Section II gives an overview of WEC energy maximising control strategies, focussing on the types of models employed, measurements (including future information) needed and computational requirements. Section III describes the prototype WEC system which is the focus of the competition, while Section IV defines the requirements, objectives and metrics of the competition. Section V gives an overview of WEC-Sim, the simulation evaluation platform, while Section VI describes the real time environment within which the shortlisted controller will be implemented. The proposed timeline and structure of the competition are defined in Section VII and, finally, some conclusions are drawn in Section VIII.

II. Control of WECs: diversity, practicality and capability

Since the early work of Budal and Falnes on reactive control and latching [18], a wide variety of algorithms for maximising the power capture of WECs have been proposed. In general, virtually all of the WEC control algorithms are model based, contrasting with the model-free maximum power point tracking (MPPT) algorithms which are available for othe renewable energy device types, such as solar panels and wind energy. This distinction, in general, due to the reciprocating nature of the wave energy flux, compared to the unidirectional flow of solar and wind energy flux. In addition, optimal WEC control, in general, requires future knowledge of the excitation force experienced by a WEC, due to the non-causal nature of the optimal control calculation [6]. These two basic requirements, of a mathematical WEC model and an excitation force forecast, immediately present the WEC control problem as comparatively (compared to other renewables) difficult, bringing the requirements for an accurate mathematical model of the WEC, which is valid over the complete operational space, along with estimation and forecasting of the (physically unmeasurable) excitation force. Add in the requirement to observe physical (force, velocity, displacement) constraints, the nonlinear nature of WEC hydrodynamics and PTO systems, the multi-form nature of the PTO power train and the wide diversity of WECs (both in terms of geometries and operating principles) and the totality of the control problem begins to become daunting. Further complications arise due to the generally feedforward nature of WEC controllers (where optimal velocity profiles are calculated based on excitation force estimates), since feedforward controllers don't generally enjoy the same level of robustness to modelling errors as feedback controllers do, and the WEC controller must also be robust to excitation force forecasting errors [8]. One further exacerbating factor is the difficulty of implementing reactive control, where power flows bi-directionally through the PTO. Reactive power flow can lead to very high peak PTO power tolerance [19] and can significantly increase the capital cost of PTO systems. While, for use with simpler unidirectional PTO systems, unidirectional power flow can be incorporated as a constraint in some WEC controllers, it can also significantly increase the complexity of the numerical search problem [20]. On the positive side, the real-time control of WECs does not present too challenging a computational problem, with sampling rates for a full-scale device no greater than around 1 Hz for the main fluid/device dynamics, though substantially faster dynamics are present in electrical/electronic subcomponents of the PTO system. Nevertheless, real-time computational challenges exist, particularly where on-line numerical optimisation is employed within WEC controllers [21].

Regardless of whatever level of WEC controller customisation might be required for any particular WEC, some level of compromise must be achieved in the controller to deal with the real-time computational requirements within an environment containing significant uncertainties (due to nonlinearity, modeling errors, etc), a limited set of measurable variables, the need to observe physical constraints, and the need to operate over a wide spectrum of sea states, each containing a spread of wave frequencies. By way of some examples, the algorithm in [22], though suboptimal, has the benefit of causality and has a feedback structure, and can handle limited nonlinearity in the restoring force term, but has no means to deal with constraints, while the algorithm in [23] solves a non-standard linear quadratic Gaussian (LQG) problem to achieve a causal controller which can handle non-ideal PTO efficiency, with a suggestion that device constraints can be considered. The algorithm in [24] can deal with constraints and models the excitation force as a narrowbanded variable frequency signal, achieving a significant simplification, while a version which explicitly deals with modelling uncertainty is presented in [25]. A wide variety of WEC control algorithms, based on various adaptations of the model-predictive control (MPC) formulation developed for the process industries, have been developed [26], while pseuspectral variations appear to have some computational advantages [21], by virtue of parameterising the system variables using pseudo-periodic basis functions, which represent typical variable time profiles driven by real sea states.

One perspective on WEC controllers is that there are complex algorithms, utilising complex WEC mathematical models, and employing computationally intensive on-line numerical optimisation. In contrast, there are a significant number of simplified algorithms which deliver sub-optimal performance (under ideal conditions), but with significantly less demands on computation and WEC model fidelity. Which of these categories (complex/simple) can better deliver real world performance, under real world requirements? This is one of the questions that the proposed control competition hopes to answer. However, one should also bear in mind that controlling

devices on smaller scales (typical of wave tank experiments) can be significantly more challenging than controlling devices at full scale. While forces, etc are significantly less (handled by the rating on the PTO system), other parasitic effects, such as friction can be disproportionate. Also, resolving smaller movements, forces, etc may result in lower signal/noise ratios on measurements.

There are a number of WEC optimisation related to control that this competition *d*oes not attempt to address, but are nonetheless important, and deserving of mention. The two-level (torque/speed) control typical of wind turbines, where converted energy is maximised for low wind speeds, but pitch control utilised to limit converted power to rated power for higher wind velocities, could be employed with WECs, in particular those which present possibilities for dynamic reconfiguration, such as shown in [27] and [28]. It has also been shown that there is significant interaction between the WEC control system employed and both the optimal device geometry [29] and optimal array layout [30]. These issues begin to address the ultimate objective of WEC control, which is to minimise the levelised cost of wave energy [31], rather than merely maximise conversion efficiency. Finally, WEC controllers can be tuned to be more or less agressive in maximising power capture, at the potential expense of extra wear and tear on the system, with subsequent operational cost implications. Thus a balance needs to be found between minimising operational costs, while maximising energy receipts. While such a balance is not fully captured by the WEC controller performance metrics suggested in Section IV-B, some impact of controller action on both capital costs (e.g. peak PTO force) and operational cost (e.g. RMS PTO force) is considered.

III. Target WEC system

A. System description

The system to be used in the control competition is a single degree of freedom (DOF) wave-activated body WEC (Fig. 1). Though, hydrodynamically, there are multiple degrees of freedom, these are not independent, and are resolved into a single PTO degree of freedom. The device comprises a floater mechanically hinged to an out of the water fixed reference point (point A). At equilibrium the floater arm stands at approx. 30° with respect to the water line. The submerged volume of the floater resembles a hemisphere. The system is equipped as follow:

Linear Motor and Controller LinMot Series P01-37x240F and LinMot E1200
Force Sensor s-beam load cell, Futek LSB302 300lb, with SGA Analogue Strain Gauge Amplifier
Position Sensor MicroEpsilon ILD-1402-600
I/O board DAQ NI PCI-6221 DAQ
Accelerometer Dual-axis accelerometer, Analog Devices ADXL203EB

Additionally, real-time information about sea surface elevation at 3 points upwave of the floater will be provided using wave gauges of resistive type.

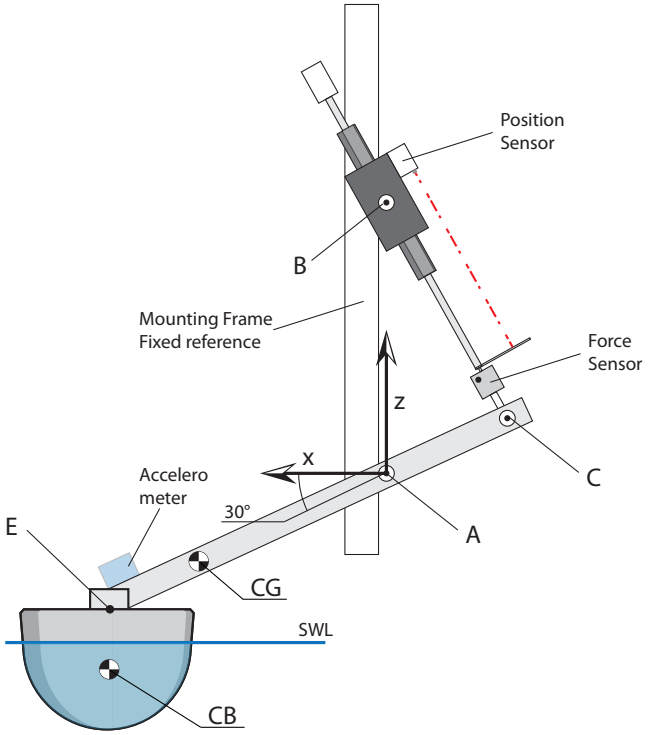

Fig. 1. Diagram of experimental WEC system.

The linear motor, (Power Take Off - PTO - system) can be driven either as a force or position follower. For the case of the force follower, the target force can include a reactive power term. While the actuator can provide up to $\pm 200N$, the force provided by the actuator will be constrained in the more realistic range $\pm 60N$. Relevant dimensions and mechanical properties of the system are listed in Tab. I. Note that those linearly measured position and forces will be converted into the control moment and the angular motion of the WEC through a fully-nonlinear trigonometric calculation.

B. Hydrodynamic model form

The floater-wave interaction is modelled by decomposing the overall hydrodynamic force in three main (uncoupled) components.

Hydrostatic Force - related to the buoyancy and gravity forces acting on the system.
Radiation Force - generated by the body motion in calm water
Excitation Force - exerted by the passing wave on a lock-in-position device.

The radiation force is further decomposed into a contribution proportional to the body velocity (radiation damping) and one proportional to the body acceleration (added mass). Similarly, the excitation force is made of the diffraction force and the Froude-Krylov force. These two terms are complementary in function of the ratio body size - wave length.

TABLE I
DIMENTIONS AND MECHANICAL PROPERTIES OF THE WEC.

Parameter	Value [Unit]
Floater Mass	4.0 $[kg]$
Mass Moment of Inertia wrt A	1.0 $[kgm^2]$
$\lvert\overline{AB}\rvert$	0.412 $[m]$
$\lvert\overline{BC}\rvert$ at equilibrium	0.381 $[m]$
$\lvert\overline{AC}\rvert$	0.2 $[m]$
$\lvert\overline{AE}_x\rvert$	0.437 $[m]$
$\lvert\overline{AE}_z\rvert$	0.210 $[m]$
Draft	0.11 $[m]$
Load Waterline Length	0.256 $[m]$
Centre of gravity CG_x	0.415 $[m]$
Centre of gravity CG_z	-0.206 $[m]$
Centre of buoyancy CB_x	0.437 $[m]$
Centre of buoyancy CB_z	-0.321 $[m]$
PTO max force	200 $[N]$
Radiation Force state space model matrices	
A_r	[-13.59, -13.35; 8.0, 0] $[-]$
B_r	[8.0;0] $[-]$
C_r	[4.73, 0.50] $[-]$
D_r	-0.1586 $[-]$

Both radiation and excitation force are frequency dependent functions. For small motions, the hydrostatic force is proportional to body displacement.

C. Hydrodynamic parameters

The hydrodynamic parameters of the considered WEC are obtained using the boundary element method (BEM) solver WAMIT.The radiation and excitation force coefficients are illustrated in the frequency domain (for model validation purposes) in Figs. 2 and Fig. 3, but can be converted to time domain quantities for use in Cummins equation (3). The calculated hydrostatic coefficient is 92.33 Nm/rad. The radiation frequency response function has been approximated with a second order state space model, the coefficients of which are listed in Tab. I. The model order has been reduced using the Henkel singular value analysis implemented in Matlab. The model order is in line with the suggestion provided by Yu and Falnes [32].

D. Model validation

The hydrodynamic coefficients calculated from WAMIT are compared with results obtained from experimental tests. The experimental results are shown in Fig. 2, Fig. 3 and Fig. 4. Fig. 2 shows the magnitude and phase plot of the Fourier Transform of a radiation force time series. The measured radiation force (blue line) is calculated from the total measured moment by subtracting the hydrostatic and inertial terms. On the other hand, the calculated radiation force (black line) is obtained by filtering the measured velocity time series, for the same test, using the state space radiation model. It should be noticed that the Magnitude plot is not normalised by the magnitude of the velocity signal, which is the reason for the non-smooth trend. Nevertheless, the measured and simulated radiation force show a good agreement, and thus the low order

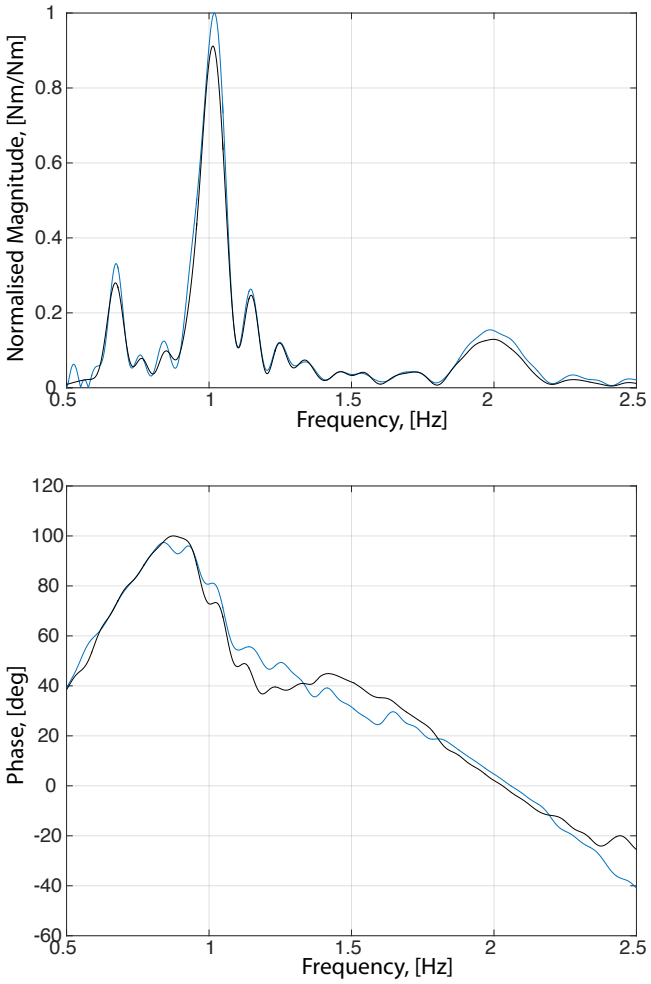

Fig. 2. Comparison between simulated (black) and measured (blue) radiation force. The frequency representation is obtained by applying the Fourier Transform to a given timeseries. TOP: Normalised radiation force magnitude. BOTTOM: Radiation force phase. The measured radiation force is obtained by subtracting the hydrostatic and inertia forces to the measured forces.

model of the radiation force is a valid approximation for the radiation force.

Fig. 3 shows the excitation force magnitude in function of the frequency. The figures report both the coefficients calculated from the BEM solver (black) and the results obtained from lab tests (blue). In this case the measurement is obtained by generating irregular waves with a floater fixed at the equilibrium position. The magnitude is then obtained dividing the Fourier transform of the measured moment by the Fourier transform of the surface elevation.

Fig. 4 shows the hydrostatic force in function of the floater displacement. The red line represent the linear approximation of the non-linear curve around the equilibrium position.

It is important to notice that all the hydrodynamic coefficients are calculated using the assumption of small motion around the equilibrium position that allow for linearisation of all the force components.

In this last figure, it is easy to see that the assumption of a

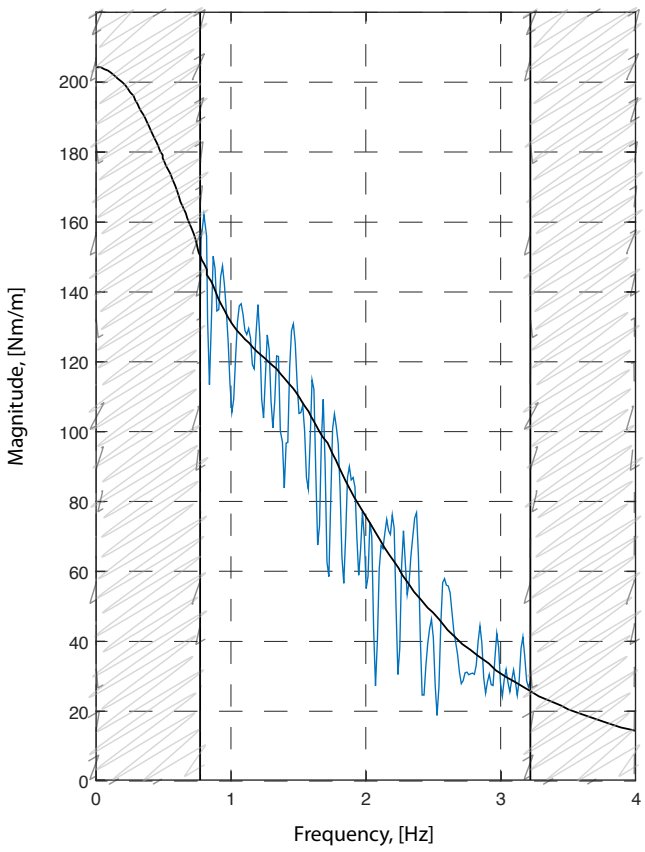

Fig. 3. Comparison between numerical (black) and measured (blue) excitation force magnitude coefficients in function of the incoming wave frequency. Within the scribbled areas, the wave energy content was not sufficient to obtain reliable results (i.e., signal to noise ratio was not sufficient).

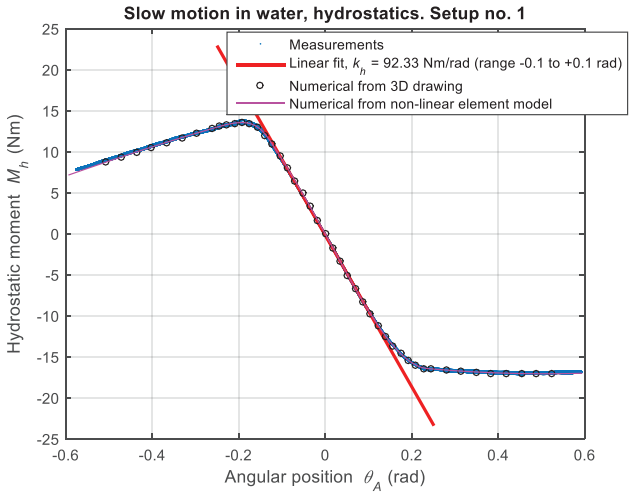

Fig. 4. Measured vs Numerical hydrostatic moment for the considered WEC.

linear relation between hydrostatic force and displacement is valid only in a bounded range around the equilibrium position, approx. ± 0.1 rad.

IV. Control competition requirements

A. Outline of requirements

Submission of control strategies will occur in two stages. In the first stage, strategies will be evaluated using a numerical model. For the second stage, a subset of the competitors from the first stage will be asked to submit a revised version of their controllers for implementation in a real-time control system, which will be evaluated through experimental wave tank testing on the physical system described in Section III. Some limitations, concerning the availability of certain Matlab library routined, will need to be considered - see Section VI.

B. Performance metrics

Applicant control strategies will be judged based on the following:

1) **Average extracted power**
2) **Capacity factor** - Peak power (95% percentile) over RMS.
3) **Peak PTO force** - The 95% percentile of PTO force
4) **PTO utilisation factor** - Ratio of peak PTO force and RMS PTO force

For each of the above metrics, contestants will be ranked based on individual performance across all sea states considered. The best performing controller in each category shall receive a ranking of 1, the second best performer shall receive a 2, and so on. Using these rankings, a final score for each contestant will be determined by a weighted sum.

$$S = \alpha_p R_{\bar{P}} + \alpha_{CF} R_{\mathrm{CF}} + \alpha_{pu} R_{F_u^p} + \alpha_{UF} R_{F_u^{UF}} \qquad (1)$$

where

$R_{\bar{P}}$ is the ranking for average absorbed power
R_{CF} is the ranking for capacity factor
$R_{F_u^p}$ is the ranking for peak PTO force, and
$R_{F_u^{UF}}$ is the ranking for PTO utilization factor,

while α_p, α_{CF}, α_{pu} and α_{UF} are weighting coefficients specifying the relative importance of the individual metrics. While the individual weightings have not yet been finalised, it is likely that:

$$\alpha_p > \alpha_{CF}, \alpha_{pu}, \alpha_{UF} \qquad (2)$$

so that a high score cannot be achieved by just having a good capacity factor, PTO utilisation and small peak PTO power, without also having a significant average absorbed power.

Control strategy performance will be assessed in a series of sea states representative of the Wavestar North Sea deployment environment [33]. A single representative result for each of the individual metrics in Equation (1) will be obtained from an occurrence weighted average from the different sea states i.e. the metrics for each sea state will be weighted by the degree to which that sea state occurrs, statistically. Only unidirectional sea states will be considered.

Contestants will be provided with the following time-dependent states and expected to provide a control input in return.

- **Position** - The position of the WEC device, as given by the position sensor in Fig. 1.
- **Acceleration** - The acceleration of the WEC device, as given by the accelerometer shown in Fig. 1.
- **Up-wave free surface elevation** - The free surface elevation will be given at 3 points up-wave from the device.
- **Actuator Position** - Position actuator with respect to the end stop position.
- **Actuator Force** - Instantaneous force exerted by the actuator on the floater.

C. Simulation performance

Simulation performance will be judged using the above metrics. In addition, a qualitative assessment of exceedance of any physical limits will be carried out, both to qualify the figure of merit obtained from (1) and also as a safeguard prior to experimental testing. State measurements will be assumed to be perfectly accurate and contain no noise. For this stage, contestants will develop their control strategies in the same Simulink/WEC-Sim model which will be used for assessment. The main reason for the assumption of perfect measurements, at this stage, is to measure maximum potential performance and to highlight any significant performance degradation, due to modelling and estimation errors, sensor noise, etc.

D. Experimental performance

Experimental performance will be judged using the above metrics. The set of sea states examined will be consistent with those used in the simulation tests. State measurements will be provided directly by sensors, and will such have imperfect accuracy and some noise. Contestants will be given the specifications of the sensors utilized to obtain state measurements. For this stage, the exact dynamics of the device will not necessarily be represented by the WEC-Sim model (i.e. some model inaccuracy will be present).

V. WEC-Sim evaluation

A. Overview of WEC-Sim

WEC-Sim is a time-domain numerical code that solves the system dynamics of WECs consisting of multiple bodies, power-take-off (PTO) systems, mooring systems, and control [34]. WEC-Sim was developed in MATLAB, and the requires the toolboxes listed in Table II. The dynamic response in WEC-Sim is calculated by solving the equation of motion for each body about its centre of gravity, based on Cummins' equation [35], which can be written as:

$$(m + A_\infty)\ddot{X} = -\int_0^t K_r(t-\tau)\dot{X}(\tau)d\tau + F_{ext} + F_{vis} + F_{hs} + F_{pto}, \quad (3)$$

where A_∞ is the added mass matrix at infinite frequency, X is the (translational and rotational) displacement vector of the body, m is the mass matrix, K_r is the radiation impulse response function, F_{ext} is the wave-excitation force, F_{pto} is the force from the PTO system, F_{vis} is the quadratic viscous drag term calculated using Morison's equation, and F_{hs} is the hydrostatic restoring force. For more information about WEC-Sim theory, implementation, and application, refer to the WEC-Sim documentation [34].

TABLE II
Required MATLAB toolboxes for WEC-Sim

Required Toolbox	Supported Version
MATLAB	Version 8.6 (R2015b)
Simulink	Version 8.6 (R2015b)
Simscape	Version 3.14 (R2015b)
Simscape Multibody (SimMechanics)	Version 4.7 (R2015b)

B. WaveStar hydrodynamic model

In stage one of the control competition, contestants will be provided a WEC-Sim model of the WaveStar device, shown in Figure 5. The WEC-Sim model solves for the WaveStar's dynamic response when subject to incident waves, and provides an interface development of the controller. Since stage one of the competition is based on a numerical simulation of the stage two experiments, the WEC-Sim model has been developed to match the experimental setup shown in 1 as similarly as possible. This means that the input signals available for the controller from the experiments, will also be available numerically via WEC-Sim in stage one. Although it is the linear force and position in the piston direction that is directly measured on the setup. However, those values will be converted into the moment and the angular motion of the absorber for the controller. The controller should only provide feedback moment back into the WEC. The convertion will be done using a fully-nonlinear trigonometric calculation scheme provided by the testing team.

The WEC-Sim model consists of $body(1)$, a hydrodynamic body for the float, and three non-hydrodynamic bodies $body(2)$, $body(3)$, and $body(4)$ corresponding to rod EC, rod CB, and the frame respectively. The experimental setup includes three hinge joints at points A, B, C. Each of these joints are modeled as revolute joints in WEC-Sim, corresponding to $contraint(1)$, $contraint(3)$, and $contraint(2)$. The WEC-Sim model also includes two fixed joints, one to fix the float to rod EC ($contraint(4)$), and one to fix the frame to the seafloor ($contraint(5)$).

C. Controller development

For stage one of the competition, contestants will be responsible for developing the $Controller$ subsystem shown in Figure 5. The I/Os for the controller are listed in Table III, and correspond to the signals passed into and out of the WEC-Sim $Controller$ subsystem. Since WEC-Sim is developed in MATLAB/Simulink, the controller must be compatible with the MATLAB/Simulink environment. Contestants may develop their control algorithm within the MATLAB/Simulink environment, or externally (e.g., dynamic-link library) as long as it is able to interface with the WEC-Sim model. The output

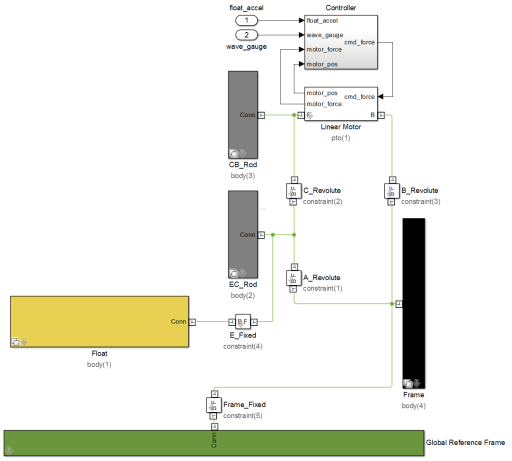

Fig. 5. WEC-Sim model of the WaveStar device. Note: The controler only reguires the angluar motion and the moment of thge WEC. The convertion will be done using a fully-nonlinear trigonometric calculation scheme provided by the testing team.

to the $Controller$ subsystem shown in Figure 5 is commanded force cmd_{force}, however per competition rules, the output can also be commanded position cmd_{pos}. A WEC-Sim model for each commanded control signal will be provided to contestants.

VI. Implementation environment

The main objective of the control competition is to test, verify and calibrate control algorithms on the prototype hardwares, where the goals of the controllers are listed in Sec. IV-B. To achieve this objective a rapid control prototyping (RCP) architecture is used. RCP allows to import a controller, which has been tested in a numerical environment, on a real-time operating system connected to a real-world input/output interface. This step is of paramount importance because any numerical model is only an approximation of the corresponding real-world system.

RCP has been implemented in Matlab/Simulink (version R2015b), using the xPC Target toolbox; the RCP architecture is sketched in Fig. 6. The hardware WEC comprises of sensors, floater, mechanical and structural elements, linear actuator and related controller. The WEC is interfaced to the Target PC via a I/O board. The Target PC runs a hard real-time OS and it embeds the controller under development. The base target PC sample frequency is 1kHz, while the controller sample frequency depends upon the computational cost of the controller itself, e.g. a simple linear damping control can run as high as 1kHz. Nevertheless, it should be notice that the sampling frequency of the controller must be an integer divider of the base sampling frequency in the target PC.

The Target and Host PCs communicate through a local intra-net connection. The controller under development is implemented in the Host PC, using a Simulink block diagram and then deployed on the Target PC as a compiled code. Once

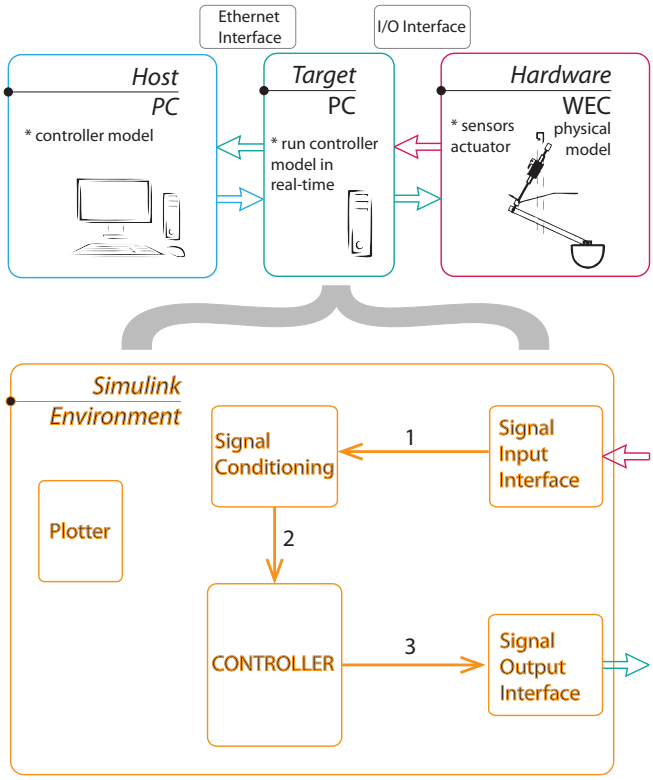

Fig. 6. Top: Simplified block diagram of the Simulink xPc target Rapid Control Prototyping Architecture. Bottom: High-level Simulink development environment.

running, the controller parameters are accessible (modifiable) from the Host PC. The Target PC

The bottom part Fig. 6 represents the high-level Simulink block diagram. The measurements from the Hardware are collected (line 1) and sent through the signal conditioning block. Line 1 comprises the linear motor rod relative position, the force balance at the load cell, the linear acceleration of the floater and the wave gauges signals; all the signals are in volt. Within the signal conditioning block calibration functions, geometrical transformations and LP filters are applied. A state observer is used to retrieve information about system velocity. The output signal (line 2) comprises angular displacement, velocity and acceleration, moment and water elevation at the measurement point; all the rotation and moments are given wrt the pivoting point A. Line 2 represent the input to the Controller block, where the control algorithm provided by the Control Competition User is implemented. The output of the Controller block (line 3) is the reference force/position used as reference for the internal control loop, within the signal output interface block. For sake of simplicity the interface of the Controller block is summarised in Tab. III

It is important to notice that not all the Simulink libraries and Matlab functions are compatible with the xPC toolbox, due to limitation in the compiler engines. This should be taken into consideration during the code development phase, a list of supported toolboxes and functions can be found in the Matlab-

TABLE III
CONTROLLER INTERFACE DEFINITION.

Signal	Unit
Input	
Angular Displacement	rad
Angular Velocity	rad/s
Angular Acceleration	rad/s^2
Resultant Moment	Nm
Surface Elevation at the selected location(s)	m
Output (either Moment or Position)	
Reference Moment	Nm
Reference Position	rad

R2015b documentation or at https:// se.mathworks.com/ products/ compiler/ supported/ compiler _ support.html.

VII. PROPOSED COMPETITION PARAMETERS

This paper is designed to serve as an initial announcement of the control and to provide the broad parameters and scope of the competition. It is anticipated that the competition proper will be launched on 1st October (provisional date) which will provide some time for any feedback or suggestions to be communicated to the competition organisers which might improve the appeal and smooth running of the competition. It is also anticipated that, following the formal competition launch, there will be approximately 6 months for competitiors to develop their controller entries, after which the evaluation period will begin. It will likely be a requirement that competitors will be asked to submit the evaluation metrics for their controllers (from WEC-Sim) as this will significantly speed up the simulation evaluation (i.e. it becomes a verification problem, rather than an evaluation problem) with an earlier return on the results from the preliminary (simulation) stage. Following publication of the shortlist for implementation evaluation, it is expected that the final wave take evaluation will take place around end May 2018, with results published shortly after.

In order to maximise the collective knowledge and experience gained from the competition, it is anticipated that the results of the competition, togther with as much detail as possible on the controller entries, will be presented at a conference and published in a journal. It may be possible to dedicate a special journal issue to the competition, with each of the finalists contributing a separate paper, as well as broader papers detailing the benchmark problem and providing a summary and comparison of results, as well as trying to encapsulate the collective experience gained and provide some broad recommendations based on the results.

A. Indicative Timeline

The indicative timeline for the competition is as follows:

TABLE IV
INDICATIVE COMPATITION TIMELINE

Date	Activity
1st Sept. 2017	Preliminary competition announcement at EWTEC 2017
1st Oct. 2017	Feedback to competition organisers
1st Nov. 2017	Formal launch of competition
1st April 2018	Entry deadline
1st June 2018	Shortlisting complete
1st July 2018	Implementation evaluation
1st Sept. 2018	Final results published

VIII. CONCLUSIONS

Open competitions provide a mechanism to test different technical solutions on a level playing field. This proposed control competition seeks to solicit a variety of technical solutions to the WEC energy maximisation problem under realistic conditions for a representative WEC benchmark problem. This paper has two principal purposes:

1) To provide a preliminary announcement and publicise the proposed competition (soliciting feedback in the precess), and
2) To provide a benchmark problem that WEC control designers can test their algorithm on

Given the significant disparity and variety of WEC prototypes, it is unlikely that this competition will provide a panacea for all WEC systems. However, at the very least, it will provide a comparison of various proposed WEC control algorithms for a particular (representative) WEC system under realistic conditions of sea conditions, available information, and model imperfections which will help to provide a guide to promising directions for future WEC control systems research.

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