ID33- DYNAMIC ANALYSIS OF A PENDULUM-TYPE WAVE ENERGY CONVERTER FOR OCEANIC DRIFTERS BY MEANS OF A 4 DOF MODEL

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ABSTRACT
Drifters are Lagrangian instrumentation widely used in oceanography and climate research. They are designed to obtain data from oceans by passively following the water currents. They provide information about the ocean surface such as currents or water temperature. One of the main challenges faced at drifter's design is their autonomy [1]. The battery exchange is not possible because of the excessively high cost, both from the economic and the environmental point of view. Therefore, some studies tried to deal with this issue by embedding a wave energy converter (WEC) on the drifter: the waves motion is used to generate power through an inner mechanism, so no battery exchange is needed.

SARTI group has been working on a double pendulum mechanism embedded into a drifter to generate power (Fig. 1). Results obtained so far have been satisfactory, reporting a mean power of 180 uW with peaks of 2.2 mW at a sea of 1.4 meters and 0.29 Hz [2]. This result can be optimized by properly tuning the system parameters (mainly inertia properties). This tuning calls for the equations that describe the motion of the drifter in the sea and its embedded pendulum They would allow numerical simulations and optimizations prior to the actual physical construction. The goal of this paper, then, is to validate such model to study the coupled motion of a floating spherical buoy with an inner single pendulum under realistic sea conditions.

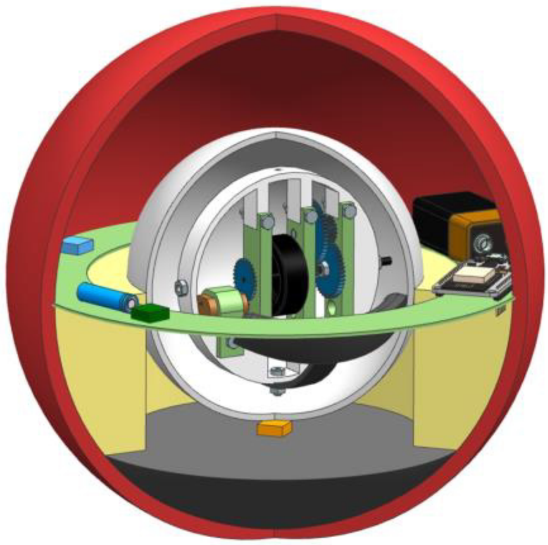

Fig. 1. Double pendulum mechanism embedded into an oceanic drifter presented at [2].

Drifters passively follow the water currents without being attached to any object. An accurate model should include the 6 degrees of freedom (DoF) (relative to the Earth) of the buoy. Also it should include 1 DoF associated to the pendulum rotation relative to the buoy. However, as a first approach, one may reduce the problem to a planar motion by just keeping 3 DoF for the buoy (the vertical translational motion, the pitch rotation and the translational motion in the direction of wave propagation) plus the pendulum rotation. Fig. 2 shows the proposed simplified model. It has been assumed that the pendulum is articulated at the buoy's geometric center (point Q). Point O is the center of mass of the buoy and point G is the pendulum's one. Z axis is always vertical and Y axis corresponds to the direction of the wave propagation. (Y, Z) are the coordinates of Q. The buoy pitch rotation around X axis is described by and the pendulum rotation by .

The validation of the model has been carried out by comparing its results with the ones obtained by OrcaFlex (Orcina), a dynamic analysis software of offshore marine systems. Both simulations use the same drifter, fluid and sea state parameters.
The model of motion of the system has been obtained using the

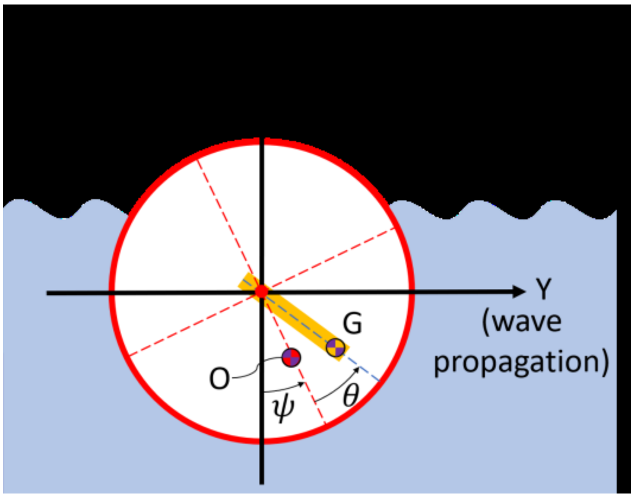

Fig. 2. 4 DoF model of the Drifter-Pendulum system.

Lagrange's equations as
where E stands for the Earth reference frame and are the generalized

$$\frac{d}{dt}\frac{\partial T_E}{\partial \dot{q}_i} - \frac{\partial T_E}{\partial q_i} + \frac{\partial U_E}{\partial q_i} = F^*_{q_i} \quad , \quad \dot{q}_i = \dot{y}, \dot{z}, \dot{\psi}, \dot{\theta}$$

forces associated with the sea-buoy interaction. This interaction may be reduced to a resultant wrench about Q with two force components (in the Y and Z directions) and one moment component (in the X direction). The small size of the drifter, with a radius of just 10 cm, allows to neglect this moment in a first approach. The fluid forces are modelled through Morrison equations [3] and Airy's wave theory [4].

The equations of motion have been numerically integrated with the fixed-step 4th-order Runge-Kutta algorithm. The sea state has been described as the superposition of two Airy waves with amplitudes Hw1=1.5m, Hw2=0.3m; periods Tw1=8s, Tw2=3.5s and wavelengths Lw1=100m, Lw2=19m. Fig. 3 shows the resulting time evolution of the drifter's 4 DoF obtained with OrcaFlex (dashed line) and through the analytical model (continuous line).

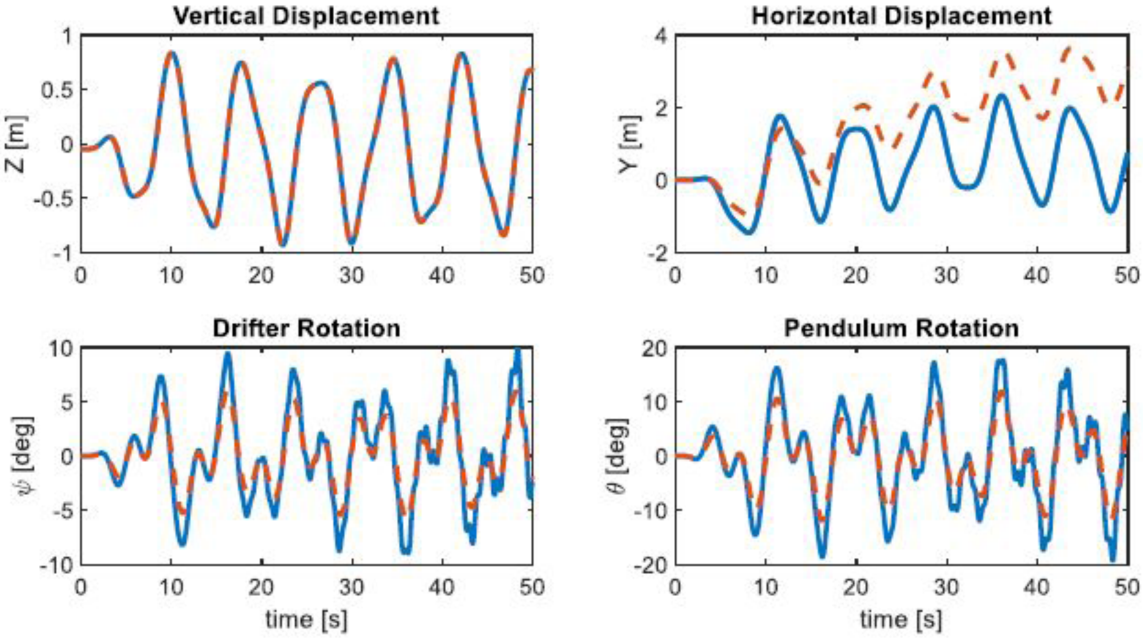

Fig. 3. Time evolution of the drifter's 4 DoF obtained by OrcaFlex simulation (dashed orange line) and by the analytical **model** (continuous blue line).

The vertical motion of the buoy's center (O) obtained through the analytical model matches with that given by Orcaflex showing an error lower than 1.5%. As for the horizontal displacement and the orientation angles (,), both OrcaFlex and the analytical simulation shows the same qualitative tendency with quantitative discrepancies. The lower amplitude values of and from OrcaFlex compared to those obtained through our model is directly related with neglecting the dissipative moment associated with the sea-buoy interaction. The higher drift of the buoy obtained with OrcaFlex is related to a different modelling of the interaction between the waves and the sea bottom. In Orcaflex, the model considers a nonsymmetric velocity profile, whereas the Morrison equations that we have implemented do not consider this phenomenon.

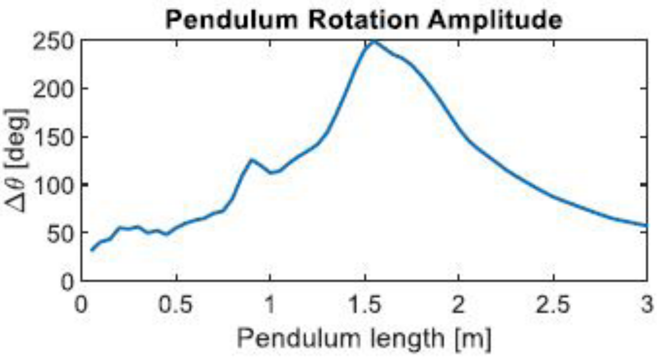

Fig. 4. Pendulum's rotation amplitude depending on its length.

As a first optimization step, we have run several simulations covering a large range of pendulum lengths (from 0.05 m to 3 m) aiming to maximize the pendulum rotation . The buoy's radius has been always two times the pendulum length while its mass has been increased to maintain the drifter's submerged volume. As does not depend on the pendulum's mass, it was kept fix during the optimization. Results are shown in Fig. 4. The maximum amplitude for is obtained at a pendulum's length of 155 cm. This is not a possibility as the common buoy's radius is around 10 cm. For this reason, a more complex pendulum's optimization is needed. Next steps include looking into the possibility of using a reduced-gravity solution or an Npendulum [5].

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