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Particles as Porpoise - Applying CFD Results to Environmental Interactions

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ABSTRACT

Individual Based Models (IBMs) provide a way of taking simple rules and principles and simulating the movement and interaction of living creatures with each other and/or the environment around them. These models have been used to investigate habitat use and movements of a variety of animals, including both marine and terrestrial mammals, fish and birds, over a range of timescales and degrees of sophistication. An advantage of this type of model is the potential to allow changes to the environment to be simulated, and potential effects of these changes to be investigated before they take place. This could include potential impacts of marine energy devices on local marine mammals.

This model uses meshes and tidal flow data from an openTELEMAC model, with the 3D mesh being composed of linear, wedge shaped elements with nodes fixed in x, y but with time varying z coordinates. Data values (such as x, y and z flow velocities, prey density or noise levels) are specified at each node and are interpolated spatially using mean value coordinates and interpolated linearly with respect to time in order to obtain values at the location of each individual animal, or boid, within the simulation. The movement of the mesh, including the changing heights of the elements, leads to a variety of issues when tracking the location of the boids within the mesh.

Key Words: *Individual Based Model, Marine Energy, Environmental Impact, Harbour Porpoise,* Phocoena Phocoena

1. Introduction

1.1. Marine Energy

The UK has access to the best wind, wave and tidal energy resources in Europe, and has a well developed renewable electricity sector[6]. In 2013, 14.9% of electricity generated in the UK came from renewable sources, with 32% of that coming from onshore wind and a further 21% from offshore wind[5]. Electricity generation from wave and tidal resources is a smaller contributor to the UK's energy needs, with current supply being limited to a small number of testing and demonstration sites, which were predicted to reach a total of 300MW of installed capacity by 2020, but with a total theoretical resource of 69TWh/year for wave energy, 95TWh/year for tidal stream devices, 25TWh/year from tidal lagoons and 96TWh/year from tidal barrages[10].

1.2. Environmental Impacts

The environmental impact of any construction or engineering project is something that should always be taken into consideration, and in many cases is a regulatory requirement. In the context of marine energy developments, an environmental impact assessment (EIA) is a legal obligation in almost all cases within the EU and the UK[2]. In part, this is due to the number of protected species and habitats that are part of the marine habitat and need to be conserved. It is also a requirement to consider the impact of a development on other people and groups using the area, which can also be investigated using the methods described below.

A typical EIA will include details on the effect of the proposed development on physical processes, including currents, changes to tidal flows, ranges and the local wave climate, sediment transport and other changes to the local water quality. These aspects of the assessment can be covered using existing, well established numerical modelling techniques combined with detailed site observations to validate the models used. Other aspects that need to be investigated cover the potential impacts on marine life in the area, such as fish, birds and marine mammals. The latter group includes both cetaceans such as dolphins and porpoise that live exclusively in water and animals such as seals, which spend time on the shoreline as well as at sea.

2. Individual Based Modelling

2.1. Introduction

An individual based model is designed to independently simulate the movements and/or states of a number of individual objects or creatures. These simulated objects, referred to as agents or boids, are designed to mimic a subset of the natural behaviour of the real objects or creatures they represent. It has previously been shown (and previously discussed in [8]) that plausible looking behaviour can be obtained from comparatively simple rules and behaviours. This has been extended by a range of other works to show that these simulated behaviours can be representative of real world animal behaviours, rather than just being visibly plausible.

A simple IBM can be described as an iterative process - At each timestep every boid acquires details about it's surroundings, applies its list of behavioural rules to that data and its position, velocity and other properties are updated accordingly. The information available to each boid during this process can be limited to restrict the simulated sensory range of each creature.

2.2. Previous Examples

It has been shown that plausible behaviours can be achieved with a small selection of rules. An early application of this technique came from work aimed at creating believable computer animations for a flock of birds. Three simple rules were implemented, and ranked in importance:[9]

1. Avoid collisions with nearby boids
2. Match velocity with neighbouring boids
3. Aim to stay close to centre of the flock[1]

While the exact rules used vary between different simulations, they serve to illustrate that reasonably simple rules can give rise to otherwise complex behaviours and patterns. Individual Based Models have been used to predict the movement of a range of animals, from larvae in complex tidal environments[11] to panthers[4]. These (and many other) examples compare favourably to field measurements of the species in question.

3. Building a Harbour Porpoise IBM

One species of interest for marine energy developers in Wales is the Harbour Porpoise (*Phocoena Phocoena*) - a small cetacean found in many coastal areas[3]. Harbour Porpoise are protected under the EU Habitats directive[1], which makes it illegal to capture, kill or disturb these animals - the potential for disturbance is one of the aspects that developers must investigate as part of their Environmental Impact Assessment, as mentioned above.

3.1. Simulated seas

In this model, boids representing Harbour Porpoise will be placed into a simulated tidal environment. This environment will be based on the output of a model in openTELEMAC - a set of simulation tools commonly used for a range of hydrodynamic simulations, including large tidal areas. The 3D meshes used by openTELEMAC consist of layers of a 2D triangular mesh, forming prismatic elements as shown in figure 1. These nodes forming these elements move vertically over time, with the uppermost layer of the mesh representing the free surface of the water. This means that elements are free to grow, shrink and move in the z-axis, but are constrained in x and y. This requires the vertical coordinates of every node to be updated at the start of each timestep and the position and/or enclosing element of each boid altered accordingly.

[1] Or the portions of the flock within the perceptual range of that boid

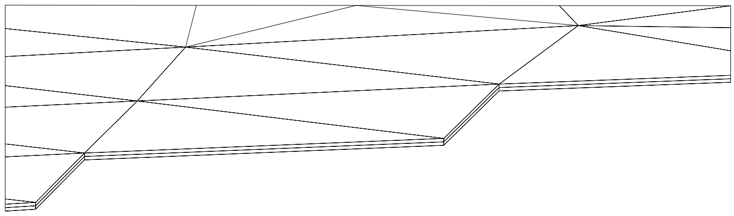

Figure 1: Slice of an example mesh, showing how the triangular faces of the 2D mesh form prismatic elements

The elements in the openTELEMAC models used have edges in the x, y plane ranging in length from 50m to 1700m, with vertical edges ranging from 0m to 40m. This presents two problems - elements with zero height and large distances between nodes and the potential locations of boids within the simulation. Dry/zero height elements are handled at the start of each timestep - the smallest vertical separation between points is calculated once the z-coordinates have been updated and stored in the element for future use. This minimum element height is then taken as the input for one of the behavioural rules, as described below.

The distances between boids and their adjacent nodes, and the potential variation in local variables that this allows, are handled using mean value coordinate interpolation. This interpolation technique takes the values of input variables at each node of an element and calculates a value at the location of our boid or test point. The technique generates smooth, continuous values for any closed polygon and any planar polyhedron[7], and allows a suitable linearly interpolated value to be calculated for the interior of any element.

3.2. Example behaviour: Responding to water depth

In order to illustrate the response of the simulated boids to changing environmental conditions, a sample set of results is presented below. These results incorporate 3 simple rules:

- Is height of element < 5m?
  - *Yes:* Head for deeper water
  - *Otherwise:*
    - Head towards greater concentrations of food
    - Minimise drag

The direction to deeper water is determined by the local elevation gradient (precomputed), and takes precedence over other behaviours. The general behaviour is subject to further work, but was implemented as a weighted average of the two conflicting aims with an additional noise term. The addition of noise to the orientation and velocity terms of the model is a common component of similar environmental models, the resulting paths are referred to as Correlated Random Walks[2] (CRWs).

The output of this example is shown in figure 2. The background mesh represents a snapshot at the end of the simulation - the depths change over the course of the simulation. It can be seen that the porpoise stay within the deeper channel when searching for deeper areas (white trails), remaining in an area to feed when those deeper areas are encountered (black trails). A small number of areas are crossed by both black and white trails - this is due to the changing water depth throughout the simulation - while some boids may enter an area when it is deeper than the threshold (5m in this instance), others may enter the area at a shallower time and continue searching for deeper water.

4. Conclusions

Although brief, the example illustrates that relatively complex behaviours can be simulated with comparatively simple rules and inputs. It also touches upon some of the additional complication encountered when applying CFD and numerical models to a realistic environment.

[2]Although porpoise swim rather than walk, the term is retained for ease of reference

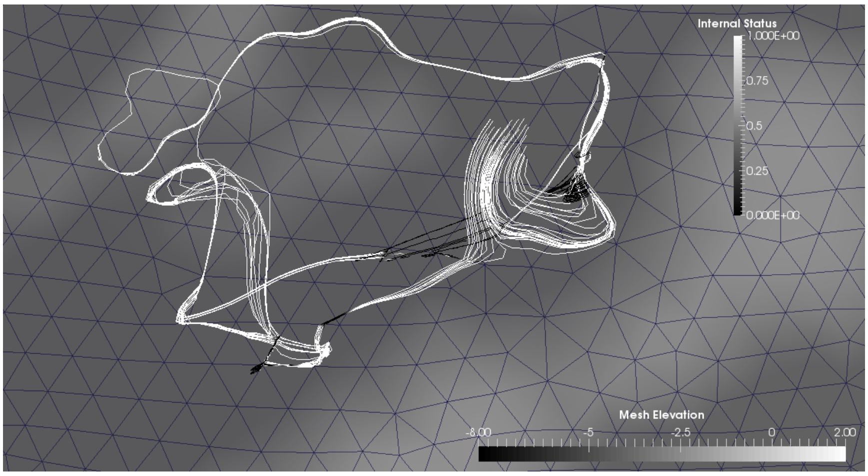

Figure 2: Example output, showing paths taken by boids representing Harbour Porpoise

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