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Partnership for Advanced Computing in Europe

SHAPE Pilot Albatern: Numerical Simulation of Extremely Large Interconnected Wavenet Arrays

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Abstract

Albatern develop novel interconnected offshore marine renewable energy devices. The goal of this SHAPE project was to begin the development of a physics code capable of simulating a large scale Wavenet array (100 or more devices) using HPC technology to extensively parallelise the solution. The simulation capability is intended to build on Albatern's in house modelling expertise, allowing the prototyping of arrays that are currently not possible to simulate due to their scale. Computer visualisation and power prediction of large scale arrays are also vital to the success of Albatern's efforts to continue investment in the technology. To facilitate development, the project was split into an algorithm development task and a HPC implementation task. The completed HPC simulation method will capture fundamental dynamic phenomena associated with arrays of wave energy devices while providing a time and cost effective development technology.

1. Introduction

Albatern is a wave energy technology company based in Edinburgh. Albatern's wave power generation product consists of buoyant Squid modules (Figure 1) which have three arms and are capable of linking with up-to three other Squids. The linking of three Squids devices forms a hexagonal arrangement. The hexagonal arrangements can inter-link to form arbitrarily large Wavenet installations (Figure 2). The Squid modules and their link-arms contain mechanisms to generate power, capturing the heave and surge motion of the waves via hydraulics. In this way, Albatern has developed a highly scalable, modular wave power generator. The company is currently involved in demonstration projects at sites in UK and Ireland.

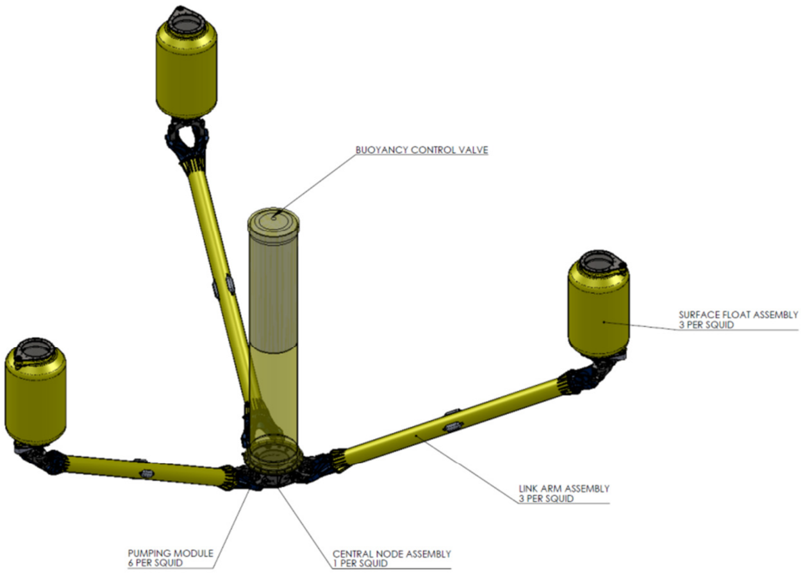

Figure 1 - The Albatern Squid module

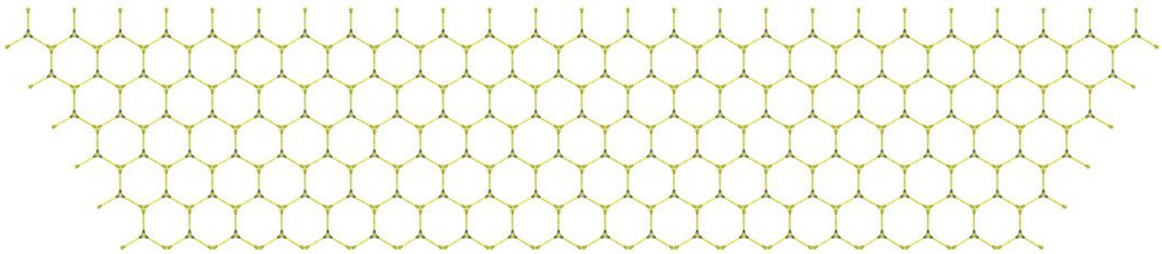

Figure 2 - An array of interconnect Squids form a Wavenet

Since the start of this project, Albatern have deployed their first power generating array off the Island of Muck, on the West Coast of Scotland. The array, comprised of three squid devices, will supply a fish farm with electrical power for running lighting and feeding equipment.

Figure 3 - Deployment of the Albatern Squid devices

Figure 4 - The 3 device array

2. Business Impact

Albatern presently employs 15 people and is currently involved in projects to deploy 9 squid modules in two small-scale wave energy array projects. Simulations demonstrating the potential cost and performance improvements gained through deploying extremely large, coupled wave energy arrays will be a breakthrough for the industry.

The computer visualisations and power generation data produced from large scale array simulations will greatly improve investor confidence and the chances of continued investment. Further investment in Albatern's technology is vital to proceed to utility scale generation projects while opening a global market valued at between £60bn and £190bn to commercial exploitation. Success in securing further funding for large scale array projects will allow Albatern to grow as a business with the opportunity to expand the scale of their projects and number of employees.

Wave energy prototypes are large, expensive and funded through risk capital. As a result prototype simulation also forms an essential part of the device design process. Computer analysis mitigates the risk of designing an inappropriate structure for its intended environment. Under-design could result in a premature failure that is an unacceptable loss for the business, while over-design increases costs significantly. An understanding of the complex dynamic relationships between the device, the environment and the national electricity grid is central to the success of the technology.

3. Work Performed

Albatern currently models Squid modules and small-scale Wavenet arrays using commercially available software such as Ansys AQUA. The data produced from the simulations is important both to estimate the loads during operation, for the design engineers, and the power output of different array configurations in a range of wave climates, when modelling techno-economics. Albatern's current modelling is limited to individual squid devices and Wavenet arrays of up to 6 devices. This is due to a hard limit on the number of free bodies that can be simulated and the computation time due to the serial nature of execution.

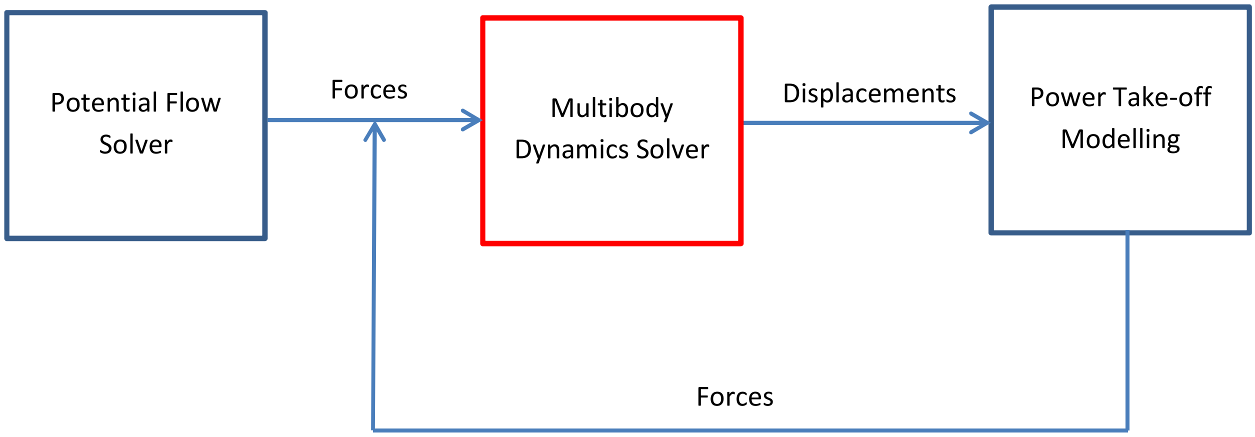

Figure 5 - The solver modules and data flow

To progress beyond the limitations of the current software, it was proposed to construct a new, modular solver capable of capturing the behaviour of large scale Wavenet arrays. The high level architecture of the completed solver is shown Figure 5. The solver module with the greatest potential for benefitting from parallelisation is the multibody dynamics solver.

The multibody dynamics solver is a computationally expensive algorithm that must resolve the complex motion of an individual Squid module. Due to the identical, modular construction of the array it was proposed to parallelise the computation of the multibody dynamics problem using the scientific computing library PETSc[2].

As the multibody dynamics solver was being developed at the same time as the potential parallelisation strategy it was decided to break the development into two halves, with Albatern developing the algorithms for the multibody dynamics solver and EPCC developing a simplified rigid body problem using PETSc. At the end of the project, the aim was to have a method to implement the full multibody dynamics code using a parallel PETSc solver.

4. An Impulse Based Multibody Dynamics Model – Albatern

Albatern has prototyped a multibody dynamics solver based on computational methods used in computer graphics and gaming, described by Garstenaur [1]. There are several perceived advantages to this approach. These types of multibody methods are currently widely being researched and improved with a large volume of publications and open source code which provide a reference for implementation.

Modern multibody dynamics algorithms are developed to complement an object oriented approach of implementation, resulting in expandable, testable, modular code. Albatern have based the first implementation of their code based on the Sequential Impulse method, an object oriented method, which is straight forward to physically implement and understand whilst proving to be high performing.

The algorithms are suitable for testing on a small scale and converting to a matrix based Simultaneous Impulse Method which is compatible with implementation in PETSc which provides a highly optimised, pre-tested parallel implementation of most linear algebra methods.

Albatern's first successful simulations were built up from single jointed pendulum problems to a single squid device interacting with an ocean roller. The visualisation below is a line plot representing the 13 bodies (red lines) and 12 hinges (green lines) comprising a Squid. The model implements a buoyancy model based on the wave interface to provide the motion of the Squid.

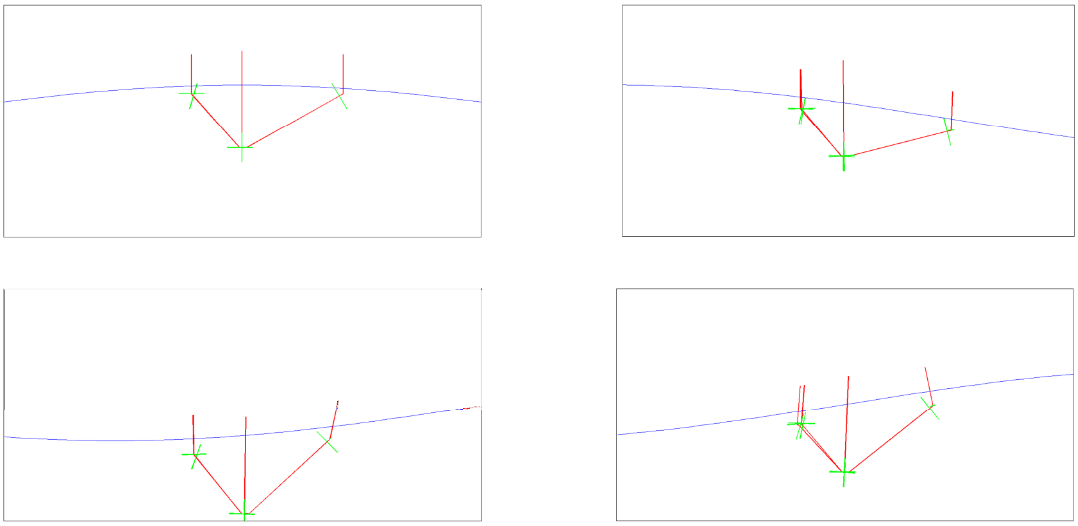

Figure 6 - A single Squid modelled against an incoming wave in MATLAB

Albatern has extended their modelling to small scale arrays in MATLAB to confirm that the chosen sequential impulse method will solve stably for arrays of closed loop, interconnected multibody structures. One of the challenges of this class of problem is solving the body motions to equilibrium as the closed loops lead to an over determined system of constraint equations. Figure 7 is an example of Albatern's 3 Squid array. Albatern has successfully simulated up to a 6 Squid array without loss of numerical stability or unacceptable positional error, confirming that the modelling approach is robust and efficient.

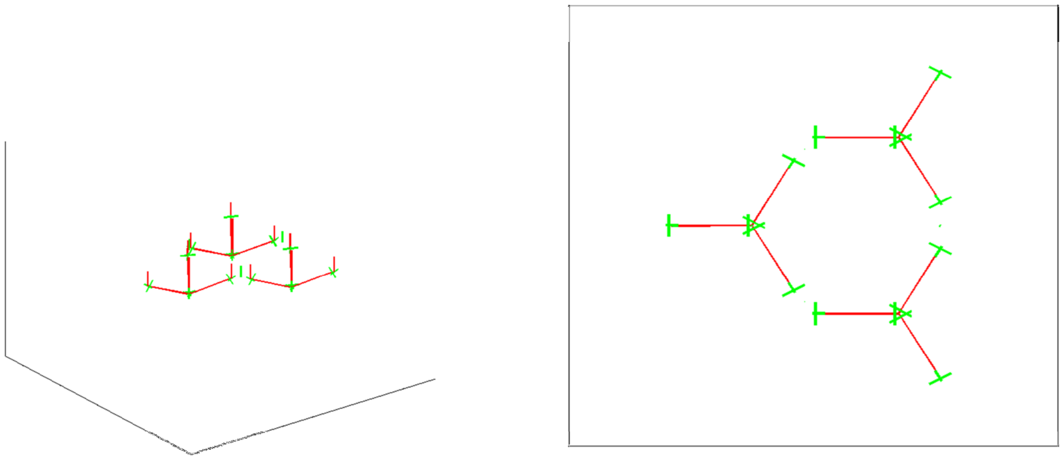

Figure 7 - A 3 Squid array modelled in MATLAB

5. PETSc Solver – EPCC

A Wavenet array consists of a number of three armed squids whose arms are connected together to form an array, plus a mooring grid anchored to the sea bed. Each squid is tethered to the mooring grid point below it. The mooring grid is illustrated in Figure 8 and Figure 9.

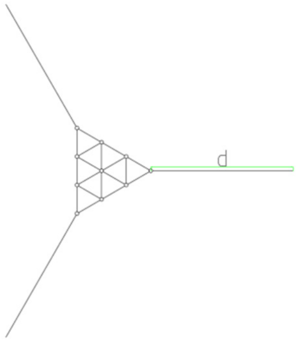

Figure 8: the mooring grid as seen from above

The long lines in Figure 8 represent the cables anchoring the mooring grid to the sea bed.

Whilst Albatern has focussed on modelling a few Squid devices in detail, EPCC was given the task of developing a simulation of a larger number of simplified devices attached to a mooring grid. This simulation was to have two important characteristics. Firstly the simulation should be easily expandable to large arrays of Squid devices and secondly it should be possible to incrementally increase the complexity of the model of the squid so that eventuallylarge arrays of complex squids could be simulated.

EPCC undertook to simulate a simplified model in which the Squid devices were replaced by barrel shaped, floating bodies. The floating bodies are connected to the mooring grid only, not to each other, see Figure 9.

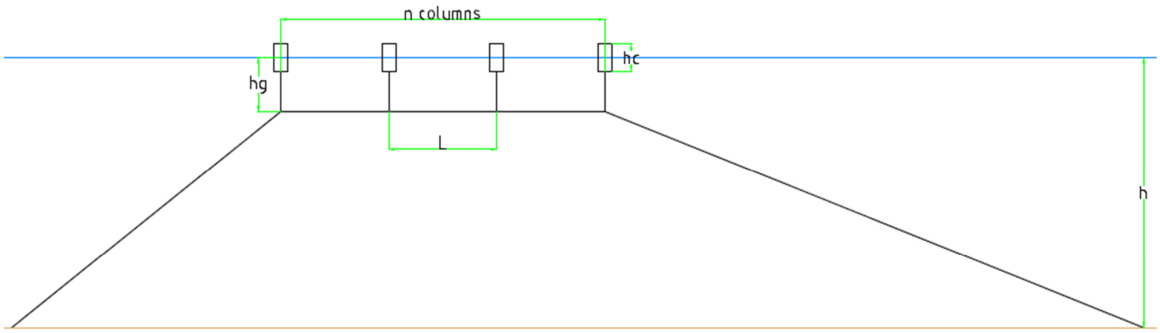

Figure 9: the mooring grid and floating bodies viewed from the side

The blue line in Figure 9 represents the surface of the water whilst the brown line represents the sea bed.

The technology selected to implement the simulation was a freely available solver library called PETSc running on ARCHER which is a distributed memory computer with tens of thousands of cores (the current code has been run on a single node of this machine which contains 24 cores). PETSc is an actively maintained system that has been under development for some time. EPCC has some experience in its use on ARCHER but not with the use of its time dependent solvers specifically. The use of these solvers is required for this application.

PETSc is fundamentally a system for solving sets of linear equations. Built on top of this are mechanisms for solving non-linear equations and time-dependent systems of first order equations. PETSc's power comes from its ability to solve these systems of equations in parallel, and from the fact that it allows different linear solvers (and preconditioners) to be used at run-time without having to recompile the code. However, in order to exploit PETSc the dynamics of the system must be expressed in matrix form in such a way that all of the variables may be updated simultaneously. Albatern's model of a Squid, as it was at the start of the project, had not been developed with this in mind and part of Albatern's work has been to reformulate their model to facilitate integration with the model of the mooring grid.

Using PETSc has its difficulties. The first problem is that way things are done using PETSc is often unfamiliar to engineers. Others are that the documentation is poor and that the system is difficult to use. However, the mechanisms provided by PETSc are needed in order to simulate large arrays and it is more efficient to use PETSc than to use bespoke code.

EPCC has developed a simulation as described above that incorporates hydrostatic and hydrodynamic forces caused by interaction with waves, elastic forces arising from the links between the mooring grid points and between the mooring grid points and the floating bodies, and gravitational forces.

The simulation has been developed in C because that is the language in which PETSc is implemented. The code has been written in a fashion that allows unit tests to be carried out and a large number of such tests have been developed. The solution generated by the code is being verified by comparison with data supplied by AlbaTERN. This comparison has not yet been completed but the indications are good and the code is now in a state ready to be integrated with the squid model.

6. Cooperation between SME and PRACE

Albatern is very satisfied with the outcome of the project as an initial interaction into developing a HPC suitable multibody dynamics solver. A clear path of development is available for Albatern to continue development of the solver.

Ideally, Albatern would have liked to have started the project with a functioning prototype solver already written in C++, ready to parallelize. This would have helped provide a more structured starting point from which to do the work and as a consequence focus more closely on working on the same programming project as EPCC.

Having said this, the basic starting problem that Albatern has chosen is useful and was successfully completed within the project scope. A more complex project may not have been possible to complete successfully in the time available. The completed code serves Albatern with a usable example with which to plan the implementation of the full multibody dynamics code.

7. Benefits

The PRACE project has helped Albatern develop in house software that will directly aid expanding the scope of their simulation capability. It has added focus and an awareness of the HPC tools, that are available and the constraints that must be met by algorithms in order to be suitably parallelizable on distributed memory machines.

Albatern is now in a position to write a multibody dynamics code that will share common parts of the simulation procedure allowing interchange of either the simultaneous or sequential methods. The ability to write both shared memory and distributed memory versions of a parallel multibody dynamics code is also possible, maintaining the widest range of simulation options.

8. Future Actions

Albatern intends to continue developing their code towards a PETSc implementation in the future. This will be achieved by:

- Implementing the prototype Sequential Impluse solver, written in MATLAB, in C++.
- Writing the key components of the solver using matrix methods.
- Converting the relevant parts of the the solver to use appropriate PETSc libary methods.

9. Conclusions

In this PRACE SHAPE pilot project the partners have attempted to define and construct a multibody dynamics solver suitable for parallel execution on distributed memory systems. The approach taken was to split the work into two areas: one looking at algorithm development and the other implementing a PETSc based rigid body model. On the algorithm front, a sequential impulse method was developed and confirmed to adequately simulate the close loop array structure of an Albatern Wavenet array. These sequential impulse methods can be written in matrix form in order to take advantage of the matrix methods provided PETSc provides. In addition, a rigid body simulation was created to model the underlying mooring grid, and to demonstrate how to integrate with the PETSc library. Albatern plan to continue this work, focussing on integrating the most effective multibody dynamics methods with the PETSc-based framework already developed.

References

[1] A Unified Framework for Rigid Body Dynamics, Garstenaur H., Masters Thesis, University of Johannes Kepler, Linz, March 2006

[2] PETSc, Portable, Extensible Toolkit for Scientific Computation, http://www.mcs.anl.gov/petsc/

Acknowledgements

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