Faster than Real-Time Coastal Wave Visualization with a Phase-Resolving Boussinesq-type Model

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LONG-TERM GOALS

This project is driven by the desire to develop a phase-resolving, nonlinear and dispersive wave model for immediate and interactive prediction of coastal wave heights, breaker locations, and wave-induced currents - that can run on laptop and tablet hardware. Such a tool would allow for rapid simulation of complex coastal conditions, either in the office or in the field, and might further our ability to perform realtime coastal wave predictions with forward-looking windows on the order of minutes, if combined, for example, with a coastal radar system.

OBJECTIVES

The main objectives of this effort include:

- Creation of a "fast-Boussinesq" code for use on multi-core CPU's using modern Finite-Volume techniques
- Porting of the CPU code for use on GPU's, where early work has indicated model speeds in exceed of 100 times faster than real time
- Inter-comparison of the fast CPU model, the GPU model, and previously developed high-order Boussinesq type models using data from the New River Inlet field study.

The anticipated outcome of this proposed effort will be the development of two, fast-Boussinesq solvers, one that uses CPU's and a another that uses GPU's. The models will be structured to use standard input and output formats, such that they might be incorporated into established user interfaces (e.g. Delft Dashboard). Through this interface, the user can chose which version of the code to use depending on their local hardware.

APPROACH

Boussinesq-type models found in many applications are high-order variations requiring similarly high-order numerical schemes. While these approaches provide the research-level accuracy needed for certain studies, they do not provide a means for rapid computation; real-time simulations of a modest coastal region can only currently be achieved with parallel processing on dozens to hundreds of cores.
We will utilize a modified form of one of the earlier versions of the Boussinesq-type model (circa early 1990’s), but combined with recent numerical solution techniques to maximize computational solution speed.

The model to be solved will be the weakly nonlinear Boussinesq-type model, without the Nwogu-type modifications. While disregarding the Nwogu-type modifications yields a model with decreased dispersion accuracy for intermediate water waves, it also yields a model without third-order spatial derivatives. It is these derivatives that induce huge computational cost. The numerical solution scheme – spatial derivatives and time integration – must be fourth-order accurate to prevent numerical errors that appear similar to these “real” third-order derivatives.

The to-be-employed Boussinesq equations will be re-cast in conservative form as shown below:

\[
\begin{align*}
\frac{\partial H}{\partial t} + \nabla \cdot H\vec{U} &= 0 \\
\frac{\partial H\vec{U}}{\partial t} + \nabla (H\vec{U} \cdot \vec{U}) + gH \eta + H \left[ \frac{d^2}{2} \frac{\partial (\nabla \cdot \vec{U})}{\partial t} + \frac{d}{6} \frac{\partial \nabla (\nabla \cdot (d\vec{U}))}{\partial t} \right] &= 0
\end{align*}
\]

Where \( H \) is the total water depth = \( \eta + d \), \( \eta \) is the free surface elevation, \( d \) is the still water depth, \( \vec{U} \) is the depth-averaged velocity vector, and \( g \) is gravity. To solve this equation set, we will use modern Finite-Volume (FV) techniques, such as those used in the PI’s previous modeling efforts (e.g. Kim et al, 2009). The advantage of using the FV method for the work proposed here is that they can be extremely robust when implementing certain flux reconstruction and limiters. Here, “robust” implies that numerical dissipation keeps the solution stable and smooth. In addition, FV limiters can be used as a proxy for coastal wave breaking. In conventional Boussinesq-type modeling, breaking is approximated with ad-hoc dissipation submodels (e.g. Kennedy et al, 2000). While these submodels are shown to be accurate, they also add a substantial computational and memory cost to the numerical solution. While modeling wave breaking through FV limiters (i.e. numerical dissipation) is not preferred from a physical accuracy perspective, such an approach can be tuned for reasonable breaking prediction for a defined range of grid sizes and wave periods in shallow water.

Initially the model will be coded for use on multi-core CPU’s, as nearly all laptops and desktops now contain. This code is considered the “general-use” code, and can be easily executed on all platforms. Efficiency and speed of this code will be tested, using a domain on the scale of New River Inlet. Comparisons between this proposed model, Lynett’s high-order models, and the RIVET I field data will provide benchmarks on model accuracy and applicability. After this effort, the fast-Boussinesq code will be ported to the Graphics Processing Unit (GPU). Lynett’s research group has already developed and tested a Nonlinear Shallow Water (NLSW) wave equation model on the GPU. An example of the NLSW GPU solution is online here: http://www.youtube.com/watch?v=nM21JeUHzys&feature=youtu.be. The shallow water model runs at \(~250\) times real time on a high-end GPU card for a domain on the scale of New River Inlet (\(~10\) km\(^2\)).

**WORK COMPLETED**

This project was initially funded in May of 2014, and thus limited work has been completed during the first five months of the project. To date, we are in the process of developing the CPU version of the
fast-Boussinesq model, using the numerical scheme found in the GPU-version of the already-developed shallow-water model. This scheme has the advantage of a proven GPU implementation, and it is expected that once we are able to properly incorporate the Boussinesq dispersive terms into this numerical framework, that a GPU version of a “fast” Boussinesq model will follow. A snapshot of the GPU-based visualization model is shown in Figure 1.

RESULTS

As noted above, the project was initiated less than four months ago, and there are not yet any substantial or complete results of the effort.

IMPACT APPLICATIONS

It is expected that the Boussinesq model will be on the order of ~100 faster than real time on the same platform, and probably ~10 faster than real time with low-end mobile hardware. A primary advantage of the GPU solution process is that one can perform the visualization as part of the model solution. If visualization is the primary objective, and the user platform (tablets or computers) are expected to have a GPU as nearly all do currently, then the GPU-FV solution is a promising option.

RELATED PROJECTS

This modeling ability to be developed in this project will be useful for simulating the data recorded during the RIVET I and II field surveys, or any project that requires a rapid prediction of coastal wave heights.

REFERENCES


PUBLICATIONS

None yet to date

Figure 1. Example output of a wave field from the GPU-based NLSW model