Universität Stuttgart

IWS

Institute for Modelling Hydraulic and
Environmental Systems
LWW: Prof. Dr.-Ing. Silke Wieprecht
LS3: Prof. Dr.-Ing. Wolfgang Nowak

University of Stuttgart · Institute for Modelling Hydraulics and Environmental Systems
Department of Hydraulic Engineering and Water Resources Management
Pfaffenwaldring 61 · 70569 Stuttgart

Contact
Dr sc. (PhD) Sebastian Schwindt
Phone
+49 - (0)711 / 685-64789
Fax
+49 - (0)711 / 685-64746
E-mail
sebastian.schwindt@iws.uni-stuttgart.de
Date
20.09.2023

Advisors

Dr sc. (PhD) Sebastian Schwindt, Prof. Dr.-Ing. Silke Wieprecht

Department of Hydraulic Engineering and Water Resources Management (LWW)

Institute for Modelling Hydraulics and Environmental Systems (IWS)

University of Stuttgart

Title: Revolutionize Computational Hydraulics with Data-Driven Models and Video Engines

Keywords: Numerical modeling, smoothed-particle hydrodynamics, machine learning, rivers, ecohydraulics

Introduction and background

Are you ready to dive into the forefront of hydraulic engineering? In this project, the successful candidate will advance cutting-edge research tools in river hydraulics to a new level of excellence. State-of-the-art modeling of hydrodynamics builds on two-dimensional (2d) depth-averaged models and three-dimensional (3d) numerical modeling of potentially large landscapes. In this process, complex hydrodynamic equations are typically solved across a numerical grid, which necessitates significant simplifications. For instance, processes occurring between grid nodes, such as the dynamics of turbulent eddies that are smaller than the grid, are interpolated based on Gaussian statistics. However, the world does not follow normal distributions, and extreme value statistics govern our environment. This is why the so-called Reynolds averaging, which uses a mean and standard deviation (i.e., Gaussian statistics) to approximate turbulence properties, leads to high imprecision. Grid-based numerical solvers can address this inaccuracy through extremely high grid resolution but at a high computational cost.

Recent developments in machine learning offer options to circumvent the high-cost computations of grid-based models, making them attractive for optimization in this project. Additionally, grid-free smoothed particle hydrodynamics (SPH) will be employed as they are computationally more efficient, not subject to grid scaling, and can be parallelized better.

Thus, the mission of this Ph.D. project is to develop and compare computationally efficient 3d numerical modeling schemes. Specifically, grid-based techniques combined with machine learning will be evaluated against SPH performance in digital twins of hydraulic structures.

Research Goals and Methods to be Used

The Ph.D. candidate will familiarize with existing turbulence models using grid-based open-source 3d numerical modeling (CFD) software and novel grid-free SPH techniques. Study materials, guidance for model calibration and validation concepts, and in-house machine learning (data-driven) algorithms will be provided. Grid-free methods will be applied through the Niagara fluid plugin of the Unreal Engine, enabling a radical rethinking of numerical modeling in hydraulic engineering through massive parallelization and interactive exploration of simulation results.

First, a grid-based model will be set up using existing data for a fish passage structure. Second, the grid-based model will be accelerated using data-driven sub-models for turbulence. Next, a grid-free model of the same structure will be created using a virtual video engine (Unreal Engine) and SPH (Niagara fluid plugin). Comparing the computing time between grid-based models with and without data-driven modeling and grid-free methods will benchmark the first significant research achievement. The scientific knowledge gained through advancing turbulence modeling algorithms will mark the second research milestone of this Ph.D. thesis.

Ultimately, the virtual (Unreal) world will be populated with typical fish characters to quantify the flow field and identify preferable ecohydraulic conditions. Thus, one of the first fully functional ecohydraulic models will represent ground-breaking research progress and conclude a Ph.D. thesis with global impact.

References

- Gingold & Monaghan, Smoothed particle hydrodynamics: theory and application to non-spherical stars, Mon. Not. Astr. Soc. 181(3), 375–389, 1977, doi: 10.1093/mnras/181.3.375.
- Franca & Brocchini, Turbulence in Rivers, *Rivers – Physical, Fluvial and Environmental Processes*, Rowiński & Radecki-Pawlik (Eds.). Springer Int. Publishing, 2015, 51–78. doi: 10.1007/978-3-319-17719-9_2.
- Programming and modeling tutorials: https://hydro-informatics.com
- Niagara Fluid: https://docs.unrealengine.com/5.1/en-US/niagara-fluids-quick-start-guide-for-unreal-engine/

Research Environment

The Ph.D. candidate will run computer models on clusters and PCs at the IWS. Optionally, participation in fieldwork surveys can be conducted to enrich the available data for numerical model optimization. The successful candidate will be part of an interdisciplinary working group focusing on fluvial hydro-morphodynamic processes in conjecture with ecohydraulics of freshwater environments. Additionally, expertise can be inquired at neighboring groups at IWS, notably, on stochastic simulation, porous-media flow, and machine learning.

Prerequisites

Command of (fluvial) hydrodynamics, basic statistics, and programming; ideally, experience with Python, numerical CFD models (e.g., OpenFOAM), and/or the Unreal Engine.

Contact for questions

Dr sc. (PhD) Sebastian Schwindt, University of Stuttgart

sebastian.schwindt@iws.uni-stuttgart.de