Simulating Fluid Motion using Smoothed Particle Hydrodynamics

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Abstract

Realistic simulation of fluids is an important tool with a wide variety of applications such as within the Aerospace industry to model fluid based phenomena of spacecraft parts and within the computer games industry for authentic graphics. In this paper, I explore a method for simulating fluids known as Smoothed Particle Hydrodynamics (SPH) in order to better understand the mathematical theory behind Computational Fluid Dynamic methods and their implementation in an appropriate programming language, C++.

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1 Introduction

The field of simulation is one with many applications in all industries, with much overlap between Mathematics, Physics and Computer Science due to its predictable behaviour. One such application is Computational Fluid Dynamics (CFD), or in other words predicting the movement of fluids, which will be the focus for this project.

Simulating fluids involves observation of fluid phenomena such as wind, weather, ocean waves, waves induced by ships or simply pouring a glass of water. Such phenomena may seem extremely trivial at first glance, but in reality involve an extremely deep understanding of physical, mathematical and algorithmic methods.

1.1 Motivation

My motivation for this project stems from the work of Sebastian Lague [**?**]. Through his work, I was introduced to the concept of Smoothed Particle Hydrodynamics in the Computer Graphics community and was given great insight into the expectations from a project such as this. Further reading, especially into the sources of Lague, only reinforced the idea of undertaking this concept as my EPQ as it provided the overlap between Mathematics, Physics and Computer Science and because it was far beyond the scope of the A level curriculum.

1.2 Smoothed Particle Hydrodynamics

Smoothed Particle Hydrodynamics (SPH) stands out as a Lagrangian (particle-based) approach to fluid simulation, offering a dynamic method for modeling complex fluid behavior. Developed in 1977 from the work of Lucy [**?**] and Gingold and Monaghan [**?**] in astrophysics, its transformative potential was further realized in interactive liquid simulation and rendering, thanks to the efforts of Müller *et al.* [**?**] in 2003.

In SPH, the spatial domain is approximated into particles, each embodying various fluid properties like mass, density, and velocity. Throughout the simulation, these particles dynamically interact, forming a fluid-like continuum. Notably, the field quantities characterizing the fluid, such as pressure or velocity, can be precisely evaluated at any point in space by observing the overlapping influence spheres of individual particles. This intrinsic adaptability and precision makes SPH a compelling choice for simulating fluid phenomena across a spectrum of scales and applications.

1.3 Outline and Structure

I plan to code a small semi-realistic 2-D animation of an incompressible liquid in the programming language C++. This will initially involve researching SPH techniques, how they incorporate liquid phenomena and how these phenomena can be described mathematically to come up with a theoretical model. I will then implement each section of the theoretical model in C++, test its efficacy and possibly look into optimisation techniques as required. To evaluate the success of my simulation I will check the outcome of each component within the theoretical model and observe whether it performs as described. This allows my theoretical model to act as a success criteria.

1.4 Skills

2 Research Review

2.1 Why Smoothed Particle Hydrodynamics?

2.2 Softwares

2.3 Hardware

3 Theoretical model

4 Development and Testing

5 Conclusion and Final Remarks