CHALLENGES AND OPPORTUNITIES OF FLUID SIMULATION
GRAPH BASED APPROACHES

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Abstract—Fluid simulation is one of the old topics but still have wide opportunities to be researched, as fluid simulations have applications in various fields especially for experimentation, multimedia, movie, games and virtual reality. Fluid simulation become more popular when incompressible Navier-Stokes equations proposed. Many fluid simulation approaches based on incompressible Navier-Stokes equations emerge till today. This paper presents the results of a survey of several scientific articles that discuss the synthesis approach for fluid simulation, especially graph based fluid simulation. Generally, fluid simulation approach consists of physical based and synthesis based. Physical based has limitations in terms of computational cost and complexity. Researchers have proposed at least three approaches to overcome this, ie modifications to a physical-based approach, parallelization of a physical based approach, and a synthesis based approach. The synthesis approach has many approaches, including machine learning, deep learning, convolutional network, graph, etc. An interesting point for this synthesis approach is that computational cost and comoplect are significantly reduced compared to physical based, but the visualization of the resulting fluid is evident. Although this synthesis approach still has weaknesses in terms of accuracy, this method is interesting to be developed further for game and virtual reality purposes. This paper presents the challenges and opportunities of fluid simulation graph based on paper’s survey result.

Keywords—fluid simulation, approach, graph based, synthesis

1. INTRODUCTION
Visualizing real objects naturally is one of the most interesting areas of study on computer graphics. It is very useful to describe various natural phenomena such as fluid moving, omotive design, cloth simulation, and others that support academic and industrial research.

Fluid dynamics is one of the disciplines that examines the behavior of liquids and gases in a state of silence or movement and their interaction with other objects. The phenomenon of fluid dynamics has been studied since the 16th century by Da Vinci by observing the flow. Then Newton expressed the concept of Newtonian viscosity in the 17th century, and followed by discoveries by many other great scientists. Important contributions were given by Navier in 1823 and Stokes in 1845 separately. They derive partial differential equations of viscous fluid, which discuss about viscous fluid motion equations, known as the Navier-Stokes equation. The Navier-Stokes equation is the basis for the study of fluid dynamics until now.

To simulate the movement of substances that are continuum, such as fluid or deformable solid, common approaches used are Lagrangian and Eulerian. The researchers developed both of these approaches to simulate or make the fluid animation look real with low cost. Stam (1999) proposed a stable model using the Eulerian approach, and after that many researchers elaborate Stam's idea. Gingold, et al (1977) introduce Smoothed Particle Hydrodynamics (SPH) method which implemented in astrophysics. This method is a mesh free Lagrangian, where the coordinates can change following fluid movement. Monaghan (1995) for the first time implemented SPH for fluid simulation, and afterwards many other researchers used SPH with various improvisations for fluid simulation.

The Lagrangian and Eulerian approach is also known as the physical-based approach. Generally, the physical-based approach produces simulations with visible visualizations and high accuracy, but has weaknesses in terms of computational cost and high complexity. There are three ways that the researchers have proposed to overcome these weaknesses. The first way is to modify the physical-based approach, as proposed by Foster (2001), Lassaso, et al (2008), and Cohen, et al (2010). The second way is to parallelize the physical-based methods by utilizing the Graphics Processing Unit (GPU), as proposed by Qing Dai and Xubo Yang (2013) and Rustico, et al (2014). The third way is to use the synthesis method. Zhang, et al (2011) proposed fire simulation graph based. Sato, et al (2016) proposed synthesis fluid simulation flow-field-based. Grover, et al (2016) proposed synthesis fluid simulation motion graph based. Yang, et al (2016) proposed synthesis fluid simulation Artificial Neural Network (ANN) based. The synthesis approach has a positive effect on reducing computational cost, but it has weaknesses in terms of accuracy.

Many synthesis approaches are utilized for current fluid simulations, such as games, virtual reality, and other visualizations. In general, this synthesis approach fits with applications that require visualization that looks real and realtime, rather than experimental ones. Explore this synthesis method becomes an interesting thing considering the current and future needs in terms of visualization and virtual reality.

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This paper presents the results of a survey of several scientific articles that discuss the approaches of fluid simulation, especially graph-based fluid simulation. Then we elaborate the opportunities and challenges the fluid simulation graph-based.

2. SURVEY OF FLUID SIMULATION APPROACHES

Fluid is a deformable substance that flows and has no fixed shape. Fluid is divided into two categories: compressible and incompressible. The compressible fluid is a fluid whose density may change due to changes in pressure and temperature such as nitrogen and oxygen gas. While the incompressible fluid is a fluid whose density is constant against pressure changes such as water.

Navier-Stokes is the most commonly used mathematical model for fluid movement. In this fluid simulation model there are several variables that need considering such as velocity of the fluid movement, the density of the fluid, the pressure produced by the fluid, and the forces affecting the fluid. This below the Navier Stokes equation.

\[
\frac{d\mathbf{u}}{dt} + u \nabla \mathbf{u} + \nabla p = \mathbf{g} + \nu \nabla \cdot \mathbf{u}
\]

(1)

\[
\nabla \cdot \mathbf{u} = 0
\]

(2)

Fluid velocity \(\mathbf{u}\), refer to three components of velocity \((u, v, w)\), where \(u\) represent x, \(v\) represent y, dan \(w\) represent z. \(\rho\) represent density of fluid, \(p\) represent pressure, and \(\nu\) represent the viscosity of fluid. Equation (1) know as momentum equation and equation (2) illustrate the incompressible condition.

2.1 Survey of fluid Simulation approach

When discussing the continuum moving (fluid or deformable solid), there are two common approaches or perspectives used, they are Eulerian and Lagrangian. Lagrangian approach (particle based), treating fluids like particle systems. Each particle point on a fluid or solid has properties position(x) and velocity (v). Discrete particles are connected in a mesh. Eulerian approach (grid based) consider the particles as something fixed and observe the quantity attributes of fluid such as velocity, temperature, and density. They are measured measured at those points that change over time. Then semi-Lagrangian, a perspective that is also widely used, using the Euler framework but the discrete equations come from the Lagrangian perspective.

The Navier-Stokes equation is the basis for the study of fluid dynamics until now. Initially the fluid simulation was performed by physical-based method with the general approach or point of view used were Lagrangian and Eulerian. Gingold, etc (1977) introduce Smoothed Particle Hydrodynamics method (SPH) which is implemented in astrophysics. This method is a mesh-free Lagrangian, where the coordinates can change following fluid movement. Monaghan (1995) for the first time implements SPH for fluid simulation, and afterwards many other researchers used SPH with various improvisations for fluid simulation. Stam (1999) proposed a stable model using the Eulerian point of view, and after that many development researchers who developed the idea Stam. Pada 2001, Ronald Fedkiw, Joe Stam, and Henrik Wann Jensen researched about visual simulation smoke and result the natural and stable model as picture below.

![Picture 1. Smoke Simulation][5]

Jonathan M. Cohen (2010), reviewed some techniques for recomputing grid-based fluid calculations from grid-free particle simulation. Eulerian algorithm for fluid simulation with high robust level and runs effectively in GPU. Youquan Liu (2004) solve the Navier Stokes equation by using the semi Langrangian method on the GPU, so that run on a GPU with the ability to process boundary / surface changing conditions generated from gemoetric forms with parallel performance. However, this
method still has limitations if implemented for large-scale cases. A high-performance computing approach is needed to reduce time complexity and algorithms. Physical-based methods give simulations with high accuracy, but have weaknesses in terms of computational cost and high complexity. There are three ways that the researchers proposed to overcome these weaknesses, they are modifications to the Lagrangian and Eulerian approaches, parallelization techniques, and synthesis approaches.

Grid Based Numerical method has an important role in fluid simulation, although it still has limitations. Suppose a complex fluid simulation (with many grids) will take a long computational time and large memory. Fengquan Zhang (2011) propose some alternatives of solution to solve the problem by using SPH approach so result better performance. Solenthaler (2009) propose the predictive-corrective incompressible SPH (PCISPH) methode and produce better performance than common methode weakly compressible SPH (WCSPH).

Based on the survey of more than 50 scientific articles, it is seen that the research on fluid simulation has been very wide with various approaches. Software and applications are also very much produced. The fluid simulation research also has a very wide coverage. From the type of fluid such as smoke, water, or fire. Then each type of fluid has various characteristics. Suppose a fluid simulation for water, water can be viewed from water in containers, water on the beach, running water, surface water, water waves on the beach, deep sea water waves, water splashes, and others. Different types and fluid characteristics will of course affect the model and approach to be used. The picture below describe varoius of fluid simulation approaches based on survey paper.

Physical-based method produce the simulation with high accuracy but has high computational cost and complexity. At least, there are three categories of methods to overcome the limitation. They are modified physical based, paralelization, and synthesis methods. The first method proposed by Foster (2001), Lassaso, etc (2008), and Cohen etc (2010). The second method proposed by Qing Dai and Xubo Yang (2013) and Rustico etc (2014). And the last method proposed by Zhank etc (2011), Sato etc (2016), Grover etc (2016), and Yang etc (2016).

2.2 Graph based fluid simulation, challenge and opportunity
Many researchers have propose various synthesis method to produce fluid simulation with less computational cost and complexity. Some of them based on graph. For example, Zhang etc (2011) proposed fire synthesis simulation flow graph based, Sato etc (2016) proposed fluid simulation flow-field based, Grover etc (2016) proposed fluid simulation motion graph based.

Fluid simulation graph based become interesting to be researched. It has less computational cost and complexity, but produce simulation and animation with good visualization. Even though some researchers doubt the accuracy. So, graph based approach have chances to implemented in some areas which need quality of visualization more than accuracy such as games, movie, and virtuality. On the other hand the challenge is how to increase the accuracy while keep the computational cost and complexity low. The combination of graph based approach and physical based approach possible to solve this challenge.

3. CONCLUSION
Physical-based methods produce simulations with high accuracy, but have weaknesses in computational cost and high complexity. There are three approaches the researchers proposed to overcome the weaknesses, namely modifications to the Lagrangian and Eulerian approaches, parallelization techniques, and synthesis approaches.

Fluid simulation graph based produces fluid simulation with low computational cost, low complexity, and good visualization quality. The weakness is some researchers doubt accuracy. Thus condition bring the opportunity to implement fluid simulation graph based in movie and virtuality area. And the challenge is how to increase the accuracy.
4. REFERENCES