An Interactive Fire Animation on a Mobile Environment

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1. Introduction

One of the most difficult problems for computer graphics system is the physics based fluid simulations. Accurately rendering fire, smoke, and water is a challenging problem due to various subtle ways in which the fluid mechanics interact with this complex participating medium. Fluid mechanics is used as the standard mathematical framework on which these simulations are based. There is a consensus among scientists that the Navier-Stokes equations are a very good fluid flow model. Thousands of articles and books are published in many areas to compute Navier-Stokes equations with numerical methods.

Also, many fluid solvers have been proposed to compute the Navier-Stokes equation in realtime. However, the complexity of fluid formation, dynamics, and light interaction make fire and smoke simulation and rendering difficult in realtime. In an interactive fire and smoke simulation, users would like to look around and pass through them. Also, simulated fire and smoke should be realistically illuminated by light and in its own light.

The recent rapid increase in speed and programmability of graphic processors has enabled us to use graphic processing units (GPU) for more than just rendering fluids. In addition, the GPU implementation of variety for physically-based simulation outperforms implementations that perform all computations on the CPU.

In computer games, fluid-like animation, including fire and smoke animation, are commonly used for augmenting realistic scenes. As the gaming industry produces new games on mobile platforms, realistic-looking fluid simulation has become more and more important. Also, the development of mobile hardware enables us to run various application software, including interactive 2D or 3D games on mobile handsets. Although fire and smoke simulations are widely used on personal computer platforms, interactive physically-based simulation of fluids still has many problems on mobile platform. We have established effective physically-based fire and smoke simulation techniques in a mobile 3D environment.

Figure 1 shows some snapshots of our fire and smoke animation based on physically-based modeling and billboard layout in a mobile environment. The simulations are adopted on our mobile 3D game “Rupee Story,” which is a first-person adventure game. The motion of the game characters is controlled by the arrow keypad, and we can shoot using the “OK” key on the keypad. Also we can control the camera while playing the game.

Fig. 1. Snapshots of fire and smoke animation in a mobile environment.

Our fire simulation and its applications are implemented on a WIPI (Wireless Internet Platform for Interoperability), which is the standard mobile platform in Korea. Based on the WIPI platform, there are several extended platforms for mobile 3D contents, such as NF3D, M3D and G3D. Most of the mobile 3D platforms are based on the OpenGL-ES (Embedded System) Engine. Therefore, all of our implementations are based on the NF3D platform.

2. Previous Works

In this section, we present an overview of the previous techniques for fluid simulation and rendering. Modeling and animating fluids have captured the attention of many graphics researchers. However, no one has created general fluid models that are physically realistic and computationally efficient for real-time animation. Fluid simulation is a useful building block that is the starting point to simulating a variety of natural phenomena. One of the most popularly reviewed examples of computer-generated fire appears in the movie Star Trek II : The Wrath of Khan(Paramount, 1982).
Fournier and Reeves first introduced particle systems to models and rendered fuzzy objects such as fire, where the particles are motion-blurred in order to avoid temporal aliasing or strobing(Reeves, 1983; Shinya & Fournier, 1992).

A number of simulation-based methods for generating realistic fluid animation have been proposed. These techniques use computational nodes that are either fixed in space (Eulerian) or that move with the fluid (Lagrangian). Stam introduced a semi-Lagrangian technique for velocity advection coupled with a projection method for enforcing mass conserving. While this approach is unconditionally stable, it suffers from mass dissipation and excessive numerical damping, especially of the vortices that are so interesting in fluid flows(Stam, 1999).
In "Visual Simulation of Smoke" Fedkiw et al. combat this using a relatively new technique from the Computational Fluid Dynamics literature called vorticity confinement and higher order interpolation. In Computational Fluid Dynamics, the vorticities are detected and receive augmenting forces(Fedkiew et al, 2001). Foster and Fedkiw interpolated this into a water solver and added a level set-augmented by using marker particles to counter mass loss-for high quality surface tracking(Foster & Fedkiew, 2001).
Selle et al. proposed a hybrid method between the grid based method and particle method for enhancing vorticity confinement, which produces a good turbulent flow(Selle et al, 2005). They implemented large rolling explosion effects and smoke explosion using a grid and large vortex particles.

3. Stam's Stable Navier-Stokes Solver

The incompressible Navier-Stokes equations can be written as

$$\frac{\partial \mathrm{u}}{\partial t} = -(\mathrm{u} \cdot \nabla)\mathrm{u} - \frac{1}{\rho}\nabla p + \nu\nabla^2 \mathrm{u} + \mathrm{f}\,. \quad (1)$$

$$\nabla \cdot \mathrm{u} = 0\,. \quad (2)$$

with velocity u=(u, v, w), pressure p, constant fluid density ρ, kinematic viscosity, where f represents external forces that act on the fluid. Buoyancy, vorticity confinement, and gravity forces are good examples of external forces. Equation (1) is the momentum equation and equation (2) is the continuity equation. Equation (1) represents acceleration due to advection, pressure, diffusion, and external forces, respectively. Adding vorticity confinement and buoyancy as external forces produces a good appearance of turbulent flow Selle et al, 2005).
Stam described a stable numerical technique for interactive simulation of fluid motion(Stam 1999). Our fluid simulation solver is based on Stam's algorithm, which is stable and prevents numerical dissipation. Stam's stable fluid simulation solver is based on the Helmholtz-Hodge decomposition theorem(Stam 1999; Stam 2000, Stam 2002). The theorem states that any vector field w can uniquely be decomposed into the form:

$$w = u + \nabla q \quad (3)$$

where u has zero divergence. Here, u and q is a scalar field. Equation (3) means that any vector field is the sum of the mass conserving field and a gradient field. The equation can be reduced to a Poisson equation for scalar field q.
There are several kinds of fluids like water, smoke, cloud, fire, and mud. We implemented smoke and fire effects on our mobile games. The smoke and fire simulation can be easily

simulated on a billboard, because they can be easily simulated on regular grids. Also, they can be simulated using the same simulation equation, the fire equation.

3.1 Fire Equation

Generally, fire consists of the following components: fuel (F), heat (H), oxygen (O) and inert gas (G). If the fuel is hot enough and there is sufficient oxygen, then the fuel will react with oxygen. We assume that there always will be enough oxygen to react with the fuel gas, which simplifies the combustion computation. Using them up, they create heat and waste. These burning procedures are simplified when interacting with three arrays. The rate of reaction depends on the concentration of the reactants and temperature; in addition, the initial value of the fuel and heat are controlled by the game story. If we want to grow or shrink a fire, we can control it by providing much fuel and heat.

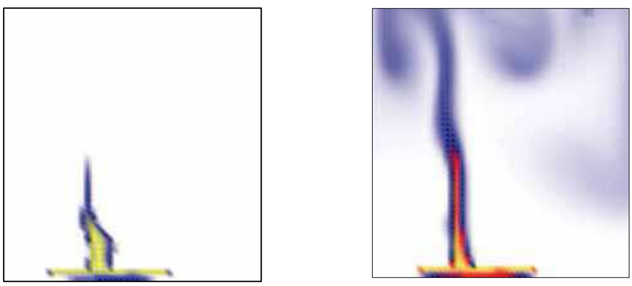
The next step is the convection step; here, we have some heat sources, which causes convection. The temperature can be converted into convection forces. There are several constants, such as an energy barrier, a rate constant, a max rate, and exothermicness, which controls various aspects of the reaction.

3.2 Coloring the Fire and Smoke

The last step is rendering. Fire has heat sources which emit light. The hotter the gas, the more energy is given off. Slightly hot gas gives off a mostly long wavelength light (infra red). As the temperature increases, it begins to give off light of shorter wavelengths: the colors are red, green (yellow), blue, and white.

The colors of the flame change, depending on its heat sources and chemical reactions. In our simulation, we implemented the gradient class to simulate various heat sources. The temperature of the fire determines the color of the flame. The fire color gradients are useful for determining various kinds of gaseous phenomena.

Figure 2 shows that various colors are implemented on our gradient class. Compared to Figure 2(a), we can see that Figure 2(b) creates smoke effects using gradient color and temperature.



(a) (b)

Fig. 2. Simulations of various chemical reaction of fire based on different gradient color. Here we can see that different colors are assigned to the core of the flame.

4. Stable Fluid Simulation on Billboards

A 3D volume rendering is widely used for realistic fire animation, but it requires much time and many resources. Therefore, the technique is not adequate for interactive games, including mobile games. Also, our technique is simulated on mobile platforms, which cannot support high resolution LCD screens. Currently, most mobile phones use 320x240 resolution LCD screens. One of the major constraints of a mobile handset is its small display device. But from the viewpoint of fluid simulation, fluid solvers do not need many grids. Hence we can save many system resources.

Two dimensional animated texture maps have been used to create the effect of the upward movement of burning gas, but such models are effective only when viewed from a specific direction. Orienting the polygon based on the view direction is called billboarding, and the polygon is called a billboard(Reeves 1983;Parent 2002)

As the view changes, the orientation of the polygon changes. Our billboard technique is combined with alpha texturing and fire animation. Figure 3 shows a billboard tree modelling on our Mobile 3D Environment.

Fig. 3. Billboard Tree modeling on Mobile Environment

Figure 4 shows the fluid animation of our billboard technique in a mobile environment. The fluid is simulated on 64x64 grid billboard. The fluids are simulated on offscreen memory and the simulated images are mapped on a screen billboard.

The red color shows the velocity field and the black and white color shows the density field. As you can see, the velocity field and density fields are changed by external forces. The external forces are added by user interactions. Also, we can see that as the view changes, the orientation of the polygon changes.

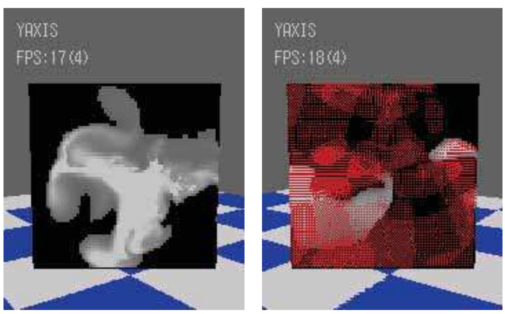
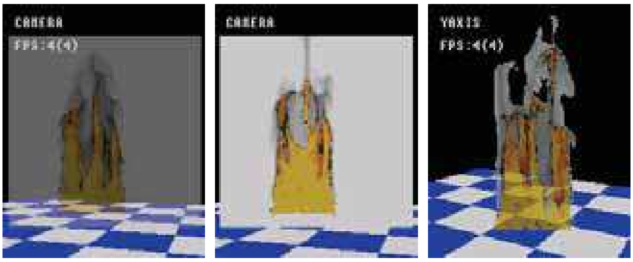


Fig. 4. Simulation of fire and smoke on the billboard. The fluid animation is simulated on a 64x64 grid billboard.

5. Alpha Blending with Background

In image based modeling, including in the billboard animation area, alpha blending is widely used for realistic looking effects with billboards and backgrounds. We used NF3D's sprite attributes for alpha blending.
Figure 5 shows the alpha blending effects of fire. Figure 5(a) is an alpha blended fire (alpha with 0.5), while Figure 5(b) does not have an alpha blended billboard (alpha with 0.0). If we apply the same alpha value on the billboard, we cannot get realistic-looking fire (see Fig 5(a)). Therefore, we can specify different alpha values to specific billboard colors (Fig 5(c)). In fire simulation, the core part of the flame emits strong lights and it has a small alpha value, while outer part the flame has a large alpha value.
We can get realistic-looking fire from billboarding and alpha blending.

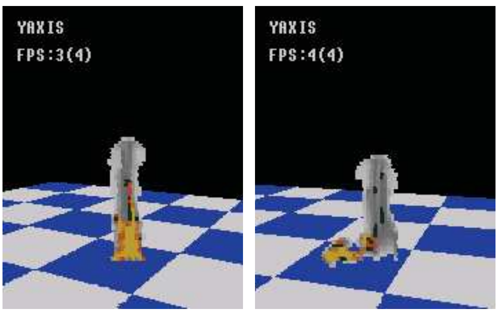


(a) (b) (c)

Fig. 5. (a) Alpha blended billboard with fire simulation, while (b) does not have an alpha blended fire with background. In figure (c), the original white background colors are erased by alpha blending.

6. Realtime Interaction with Game Characters

In computer games, interaction with characters in realtime is a very important issue. If fire and smoke animations are implemented without user interaction, they will look fake. Figure 6 shows fire animation under convection and buoyancy force. Notice that the fire's flames are moving only in an upward direction in Figure 6(a). Figure 6(b) shows the fire animation when additional external forces(like wind) are applied. In Fig 5(b), we applied external force on its left side.



(a) (b)

Fig. 6. (a) Fire animation under convection and buoyancy forces. (b) Fire animation with additional external force on its left side.

Figure 7 shows some snapshots of our mobile game "Rupee Story." As the game character approaches the fire, additional forces are applied on the fire. Therefore, it is influenced by the game character. The technique makes realistic looking fire animation in a mobile environment.

Fig. 7. The interactions are applied on our mobile 3D game "Rupee Story." As the game character is approaching the fire, the fire is influenced by the game character.

7. Performances

When simulating a fluid, the number of grid cell and the simulation time have a big trade-off. As can be seen from the results in Figure 8, the frame rate rapidly deteriorates when the simulation grid size increases.

Although a larger grid size would create a more detailed simulation, grid sizes larger than 96x96 are not adequate for interactive games on our 1024 Kb heap memory emulator. As you can see in Figure 8, less than 14 FPS animation is not a feasible frame rate for games.

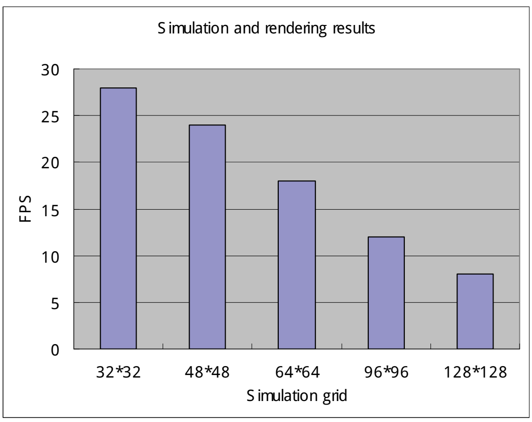


Fig. 8. Frame rates for a different implementation (on a 1024 Kb heap size).

8. Conclusions and Future Works

Physics based fluid simulations are very important but are difficult to implement for mobile platforms. We have presented a plausible physically based model for animating and rendering fire and smoke on a mobile platform. Our fire and smoke animation was also implemented on the mobile 3D game, "Rupee Story." We demonstrated that this model could be used to produce realistic looking fire and smoke animation and plausible realtime interaction for mobile games.

Currently, Korean mobile standard forums are trying to create a mobile 3D standard API(Application Programming Interface). We are also attempting to develop more realistic fluid effects on new mobile 3D platforms.

We are also trying to implement water and ocean effects on mobile platforms, which are more difficult to render and must be implemented with level-set methods. The level-set methods are very effective methods for tracking fluid surfaces, but they require many system resources.

Also, we must implement more controls for fluid simulation, including defining the fire skeleton, and detaching flames.

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Multimedia technology will play a dominant role during the 21st century and beyond, continuously changing the world. It has been embedded in every electronic system: PC, TV, audio, mobile phone, internet application, medical electronics, traffic control, building management, financial trading, plant monitoring and other various man-machine interfaces. It improves the user satisfaction and the operational safety. It can be said that no electronic systems will be possible without multimedia technology. The aim of the book is to present the state-of-the-art research, development, and implementations of multimedia systems, technologies, and applications. All chapters represent contributions from the top researchers in this field and will serve as a valuable tool for professionals in this interdisciplinary field.

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