Development of Real Time Virtual Aquarium System

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Summary
Water or any fluid similar to water in form among various fluids is highly utilized in animation production, and its application scope is quite broad. Therefore, the production of software generating fluid expression, which is easy to be intuitively used, may be quite important. Water, however, is more difficult for simulation than smoke or gas in generation of a fluid effect through an application of a fluid mechanics technique based on physics.
In addition, an excessive numerical dispersion problem should be solved. This paper presented a method to develop a fluid mechanics-based fluid expression generator and control the flow of fluid. Also, a method to build a virtual aquarium environment system that can be controllable in real time was presented by expressing the movement of seaweeds using virtual fish and control points based on the spring-mass model in this paper.

Key words:
Fluid similar, Virtual aquarium environment system, Fluid generator, Navier-Stokes, Particle.

1. Introduction

Since 80s, computer graphics have made accomplishments in entertainment industries such as film, game, and advertisements. Water, fire, explosion, smoke, fog etc as known as fluid expression technology was successfully adapted in computer animation, and these efforts contributed to increasing animation reality.
Especially, efforts to produce various fluid animation effects through hydrodynamics has increased, therefore realistic fluid effects were adapted to animation making progress. Among many kinds of fluids, water and similar form of fluids are efficient in animation making, and can be applied to various areas. Therefore development of user-central fluid simulation software is necessary. But applying hydrodynamics to water fluid effect is not capable than smoke or gas simulation, plus technical difficulty is required for excessive variance of numeric value to express natural fluid animation.
In this text, we will search for studies of realistic fluid animation techniques, develop hydro-dynamics based fluid expression creator, and introduce how to regulate flow of fluids. Additionally, from expressing Spring-mass model based simulation fish and movement of controlled seaweeds, we can find out how to establish a real-time management virtual aquarium environment system.

2. Related Work

In recent several years, studies of physical based simulation technology of various forms of fluids have been increasing. In early 80s, research of expressing sea level was done by re-modeling waves with hermeneutic functions, especially with Height field. In 86, Fournier and Reeves showed sea level by Gerstner model which explains that movement of sea level is from circle/oval shaped moving particles[4]. Miller and Pearcel introduced simple particle system model which includes interaction in limited area. Desbrun and Cani published viscous fluid flow simulation using only particle itself, and introduced Smooth Particle Hydro-dynamics[3].
Foster and Metaxas developed complete 3D water simulation with first adoption of grid in graphics[6]. Foster and Fedkiw etc solved Navier-Stokes equation - one of the most famous theory in hydrodynamics to suitable form for computer animation. And suggested answers to calculating flow of fluids like water. Stam used Semi-Lagrangian technique to solve instability occurred from current calculation of simulations and suggested simulation technique for smoke[16]. Carlson created coupling of fluid simulation and rigid simulation[2]. Terzopoulos applied simple 1D model to their spring, introduced plasticity to animation based on physics[16]. Goktekin added elasticity and related to flexible flow of Water Solver and make possible of fluid animation against non-Newtonian fluids[8]. Kothe and Brackbill studied of applying FLIP(Fluid Implicit Particle) to non-compressible fluid. In addition, they used Material Point Method(Elastic flexible limited element formula) to compressible FLIP[9].
Studies of controlling movement of fluids activated after Foster and Fedkiw suggested solution to controlling flow of fluids by determining speed level to grid cell[5]. After that, Stam and Zoran Popovic controlled smoke simulation by key frame method. Based on physics, Yongning Zhu and Robert Bridson introduced simulation of sand animation which activates similar to that of fluids[17].

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3. Virtual Aquarium Environment System

3.1 Virtual Aquarium

Virtual environment or virtual reality system let users to realize environment that not exists and enables them to experience or successfully do something. We call these experiences Sense of Presence or reality, and it may be a measure for a virtual reality system. From these reasons, virtual environment or virtual reality system requires appropriate conditions for users to realize reality. And studies for establishing reality environment are necessary.
Virtual aquarium creates many kinds of fishes living in optional virtual space, analyze their movements, carry out defining basic movement pattern of fish animation. Virtual fishes living in virtual aquarium moves in 3D virtual space and reacts as if they were alive. Through calculation of curves and materials of fish and swimming speed and direction, developers must find out flows of fluid, reason why progressing whirl appears. Those whirls are made by pressure of small whirls which is from fishes. This procedure is so complicated that it is sometimes provided with form of computer libraries.
Main purpose of this virtual aquarium system is to enjoy scenes of inside water provided by computer, plus particular interaction. In that case, the important thing is to reproduce undersea world, which is appearances and movements of fish.

3.2 Simulation of fluid

Irregular phenomena such as flow of water, movement of air, shape of clouds etc are interesting but complicated area in CG. However, CFD, formula analysis of fluid were applied to CG and more accurate depiction became possible. But since at the same condition, each material's reaction to general power varies, so it is necessary to think about character of each material and take the most appropriate formula analysis.
Fluid motion is generally studied by one of two methods. In the Eulerian method, one considers a point (x, y, z) and tries to answer questions about the properties of the fluid at this point as a function of time, such as the speed:

$$S = f(x, y, z, t) \quad (1)$$

In the Lagrangian method, one follows the trajectory of a point (x_o, y_o, z_o,), given by a reference position. This can be seen as the trajectory of a particle of matter. For instance, we can ask for the speed at time t:

$$V_x = f_x (x_o, y_o, z_o, t)$$
$$V_y = f_y (x_o, y_o, z_o, t)$$
$$V_z = f_z (x_o, Y_o, z_o, t) \quad (2)$$

And Navier-Stokes equation-general fluid simulation equation - is the most popular method to calculate realistic fluid movement of formula simulation. Following equation (3) is the Navier-Stokes equation that divides into two pieces.
First is formula related to law of conservation of mass, whatever the fluid flows, the mass remains conservate. Second is law of conservation of momentum - we can calculate velocity of the fluid.

$$-\mu \triangle \mathbf{u} + \rho(\mathbf{u} \cdot \nabla)\mathbf{u} + \nabla p = 0$$
$$\nabla \cdot \mathbf{u} = 0 \quad (3)$$

Here, U is vector of velocity, ∇ is gradient operator. First term of the second formula is about calculating viscosity of the fluid, second term is about the convection, third term is about the pressure correction. And letter represents outer force, effect from outer force to flow of the fluid.
This Navier-Stokes formula used to define at continual space, but since calculation of continual space is impossible in computer animation, we calculate this by reforming into volume date space composed by scattered grid points. By each frame, we can calculate the velocity of fluid and by this Velocity Field, rendering the shape of fluid is possible.

3.3 Boundary Condition

To express fluids with liquidity, boundary conditions are required.

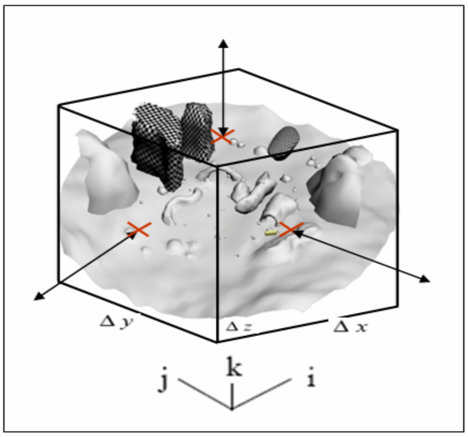

Fig. 1. The controlling boundary condition

These boundaries are composed of rigid boundary (waterproof), free boundary(composed with surface of water), inflow boundary and outflow boundary. Generally normal velocity remains 0 since water can't penetrate the boundary, and for free boundary we use interpolation and extrapolation properly. At the case of inflow boundary and outflow boundary user can control the velocity and time by option.

Fig. 2. The free boundary of fluid

Controlling the fluid's movement is also an important element as well as modeling and animating it. From the equation of defining the fluid's movement, result of the simulation is determined by establishment of the environment and basic conditions. Therefore in order to form the fluid's movement freely, basic condition and environment establishment must be considered sufficiently. Fluid simulation technology provided users to produce realistic animations automatically, but by depending too much for the simulation, there remains some problems in controlling the fluid's movement at user's will.

Velocity from particular point of an object can be divided by normal and vertical velocity, and by making these two values into parameters with proper control, modifying the velocity of fluid at that point, then user can control the fluid's flow by option. Following next figure 3. shows controlling the fluid's flow by using location, direction, velocity variables of the particle based fluid.

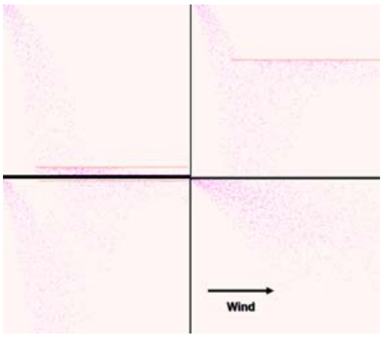

Fig. 3. Control the fluid's flow

4. Virtual Fish and Seaweeds

4.1 Spring-mass based Virtual Fish

After Reynolds' simulation of group of birds at 1987, Tu modeled physics based virtual undersea world. Artificial fishes lives in the virtual undersea world. For composing these fishes, they developed automatically moving object which is adopted AI from inside the body modeling. Virtual fish suggested by Tu is composed by physics, locomotion, perception, behavior etc. Virtual fish defined as Spring-mass model makes movement by transforming the length of spring.

In this paper, we made basic outlook of the fish by Kinetix's 3D Studio Max, made the virtual fish's movement by Spring-mass model. Virtual fish is simply composed of 3 parts head, body and fin texture rendering is by 3D vertex and mesh information, bitmap information. Figure 4. shows Spring-mass based virtual fish model for texturing.

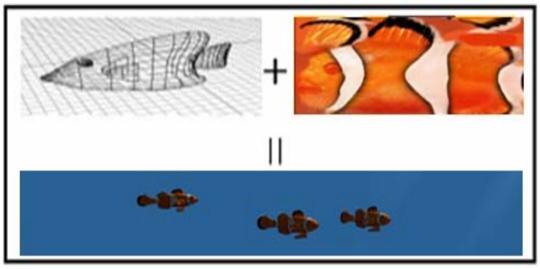

Fig. 4. Virtual fish texturing

4.2 Crowd Animation

Crowd animation is defined by providing movement of some number of characters existing in virtual environment more realistic, efficiently and more easily. For this, character animation technology related studies developing reality of the scene, capacity of the system and interaction from users are required.

Automation is necessary for providing the characters' movement by hand work is impossible in the virtual environment which requires crowd's movement. But, in case of automation of characters' movements, problems such as collision between character and character, collision between character and object, unnatural connection between unit motions or actions that not corresponds with crowds' property are need to be solved. Studies into the dynamics of fish locomotion show that most fishes use their caudal fin as the primary motivator[14]. Caudal swimming normally uses posterior muscles on either side of the body, while turning normally uses anterior muscles. To synthesize realistic fish locomotion we have designed a dynamic fish model consisting of 23 nodal point masses and 91 springs. The spring arrangement maintains the structural stability of the body while allowing it to flex. Twelve of the springs running the length of the body also serve as simple muscles

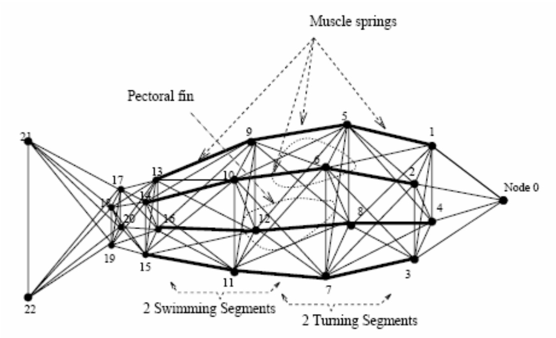

Fig. 5. The spring-mass dynamic fish model.

Improvement of the capacity through interaction of users, character's mesh data and simplification of motion is also important. But ultimate purpose of the crowd animation is reality of the scene, capacity of the system and interaction between users.

Fig. 6. The crowd animation of fish model.

4.3 Expression of Seaweed

Basic expression and production of the movement for seaweeds in the aquarium is same as those of fishes'. Movement of the fish appears dynamically in the whole aquarium but one side of the seaweed appears from both static and dynamic aspects which is limited in radius of action.

According to this, we modified Spring-mass for basic structure of seaweed expression in the text. By size of the seaweed, we divided by n-steps in order to catch a center control point on seaweeds appeared on the mesh.

By varying the action radius of the control point, we described dynamic movements of seaweeds controlled by distance and direction of seaweed that is influenced by water current in the aquarium or effect of force made by moving of fishes. Figure 7. show control point and action radius. Figure 8. shows an example of 3D seaweed expression.

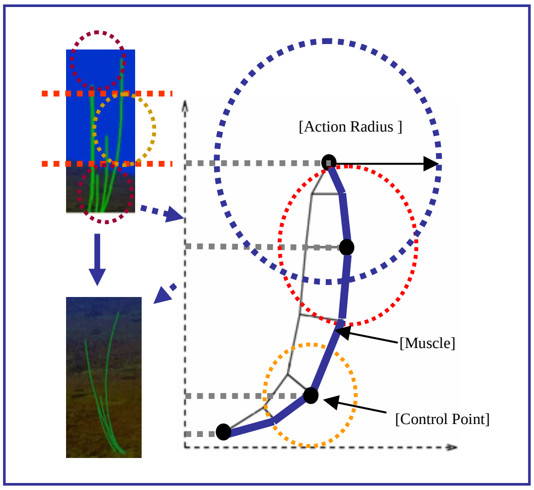

Fig. 7. Control point and action radius

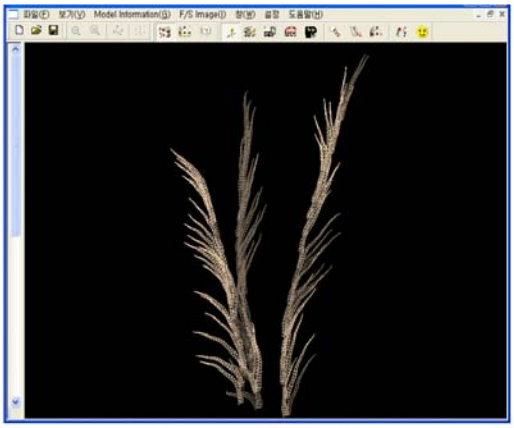

Fig. 8. The 3D seaweed expression.

5. Experiment Results

In this text, to establish realistic virtual aquarium we suggested fluid expression by hydrodynamic technique and Spring-mass based virtual fish and seaweed expression. Figure 9. is the virtual aquarium environment, Figure 10. is beginning point for user interface. Figure 11. is virtual aquarium object characters. And figure 12. is scenery of actual realized virtual aquarium.

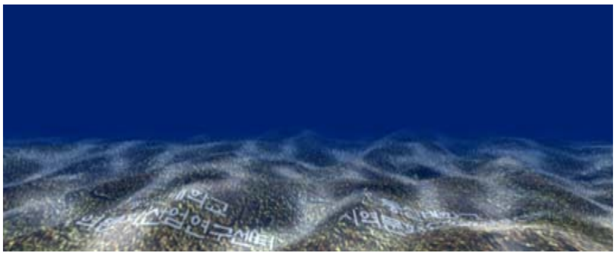

Fig. 9. The virtual aquarium environment

Fig. 10. The beginning part of user interface

Fig. 11. The 3D character of virtual aquarium(Example)

Fig. 12. The scenery of virtual aquarium

6. Conclusion

According to recent tendency of CG technology, hydrodynamics based real-time hydrodynamics simulation studies are in progress in order to applications that requires fast response such as animations, games etc. Studies are in progress not only for simple sea level modeling and simulation but also for presentation of various effects with outer factors such as interaction with other objects, climates etc. This paper presented a method to develop a fluid mechanics-based fluid expression generator and control the flow of fluid. Also, a method to build a virtual aquarium environment system that can be controllable in real time was presented by expressing the movement of seaweeds using virtual fish and control points based on the spring-mass model in this paper.

From now on, our direction of study will be for enforcing these methods introduced above. Plus, giving intelligence to fishes in the aquarium mixed with light effects or bubble occurrence so that we can produce smart fishes, and operate this virtual aquarium on the web.

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