The Framework of Sound Rendering for Particle-Based Physics

Kazuhiko Yamamoto
Graduate School of Design / ADCDU and CDS, Kyushu University, Japan

1 Introduction

There has been growing interest in the sound generating technique based on physics from the motions of 3d graphics objects. In recent work several methods have been proposed to physically simulate these audio events natably using modal synthesis [$K.\ van\ den\ Doel\ et\ al.$ 2001] or finite element method [$O'Brien\ et\ al.$ 2002]. However, in these mesh-based method, it needs complicated operation to preprocess, for example, to generate the computational mesh for 3d object, and to create the system's matrices, etc...

In this study, I present a novel idea for generating physically based sound using particle based simulation for rigid body, elastic body, fluid and their interaction dynamics. The particle based simulation treats solids or fluids as the collection of many particles. By using this type of method, we can treat various kinds of materials similarly, that have different properties respectively, and it makes much easier to discretize, to preprocess, and to implement than past mesh-based method, because all we need to initialize is to arrange particles uniformly, and as the result of that, they have uniform data structure. But it has not been contributed the idea to generate sounds from particle-based simulation method yet. So, I construct a method to simulate physical sounds from particle-based method, especially for my original orthotropic elastic model of MPS(Moving Particles Semi-Implicit) Method based solid, and it makes more easy to synthsis physical sounds in Graphics.

2 Method Overview

2.1 Sound Synthesis for Solid Motion

2.1.1 Elastic Body

For deformable body, my method is based on my original orthotropic elastic model of MPS(Moving Particles Semi-Implicit) Method. In this model, the equation for motion of particles is represented as

$$\rho \frac{\partial^2}{\partial t^2}\vec{\Psi} = E\Delta\vec{\Psi} + \nabla(divE\Psi - \nabla E \cdot \vec{\Psi}) + \eta\Delta\frac{\partial}{\partial t}\vec{\Psi} \quad (1)$$

where Δ, ∇, div represents Laplacian, gradient, and divergence respectively. $\vec{\Psi}$ indicate the displacement, ρ, η denote the dencity, and viscosity coefficient, respectively. E is orthotropic elastic tensor represented by Young modulus, Poisson rate, Shear Elasticity. This equation is discretized by replacing each differential operator using the corresponding model of the MPS method, which represent the interaction of the neighboring particles [$Koshizuka\ et\ al.$ 1999]. I define the sound pressure P radiated from a particle that locate at the surface of geometry as

$$P = \rho_{air} c_{air} \pi r_e^2 (1 + \frac{r_e \kappa}{2}) \vec{v} \cdot \vec{N} \quad (2)$$

where κ, $\vec{N}$ is the curvature and the normal vector at the point of the surface particle respectively, r_e is the threshold distance to consider the interaction between two particles, ρ_{air}, and c_{air} are dencity and sound velocity of air respectively. $\vec{v}$ denote the velocity of the surface particle calculated by Eq.(1). This sound pressure is radiated to air after processing low-pass filtering to prevent the ailiasing error.

2.1.2 Rigid Body

Rigid body is treated as quasi-elastic body, and its vibratory motion is defined as Eq.(1). Here, I construct a way to perform the modal analysis for this particle based solid. It compute the static modal analysis data by eigenvalue decomposition of linear system's matrix like as finite element technique. However, to create the system's matrix is much easier than such a solid discretized by finite element meshes because particle based solid is initialized by arranging particles uniformly. In general, linear system is represented as

$$Kx + C\frac{dx}{dt} + M\frac{d^2x}{dt^2} = f \quad (3)$$

where K, C, and M are repectively known as the system's stiffness, damping, and mass matrices, d,and f respectively as the vector of generalized displacements and forces. In MPS method, as the result of particlize, virtual springs can be defined. In my model, the coefficients for this spring within the two particles i and j is

$$Kij = E_{ij} \frac{6m}{\rho N^0 {r_{ij}^0}^2} w(|r_{ij}^0|) \quad (4)$$

where r_{ij}^0, m, and N^0 are respectively the distance of the two particles, mass of one particle, weighted dencity of neighboring particles, $w()$ denote the weighting function of MPS method. By using this equation, we can create stiffness matrix, and perform modal decomposition. Once the modal analysis data is precomputed, we can continue to use it while simulation. Each obtained mode are oscilated by forces that are given to surface particles using same technique as [$O'Brien\ et\ al.$ 2003], and radiated as sound pressure from surface particles just like the case of elastic body.

2.2 Sound Synthesis for Fluid Motion

It is well known that fluid by itself hardly makes any sound at all. It is only when air is trapped by fluid in the form of bubbles that sounds are heard [$K.\ van\ den\ Doel$ 2005]. The impulse response of radially oscillating bubble is given by

$$p = Ae^{-dt} sin(6\pi/rt) \quad (5)$$

with r the bubble radius in meters. d is the damping parameter. For particle simulation of fluid, I apply Smoothed Particles Hydrodynamics Method. To generating bubbles from fluid motion, I create air sph particles above the fluid's free surface, and when air particles is traped by fluid particles, bubble is formed. When bubble is generated, sound pressure of the bubble can be calculated by eq.(5), and radieted from the position of the center of the bubble.

2.3 Sound Synthesis for Solid-Fluid Interaction

In this method, to synthesis the sound from solid-fluid interaction, we don't need any special things. All we should is to simulate solid-fluid coupling by using arbitrary way, and by calculated forces given solid to fluid, and fluid to solid, sound pressure is computed automatically by above-mentioned method.

3 Conclusion

In this study, I presented a novel idea to generating physically based sound from particle based simulation. It makes very easy to preprocess and to implement compared with the past finite element mesh-based method because all we need to is to aranging particles uniformly. In the future, I"ll implement this method on GPU using NVIDIA CUDA, and develop a interactive application.

References

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