Interactive Simulation of the Process of Glottal Wave Generation using a GPU

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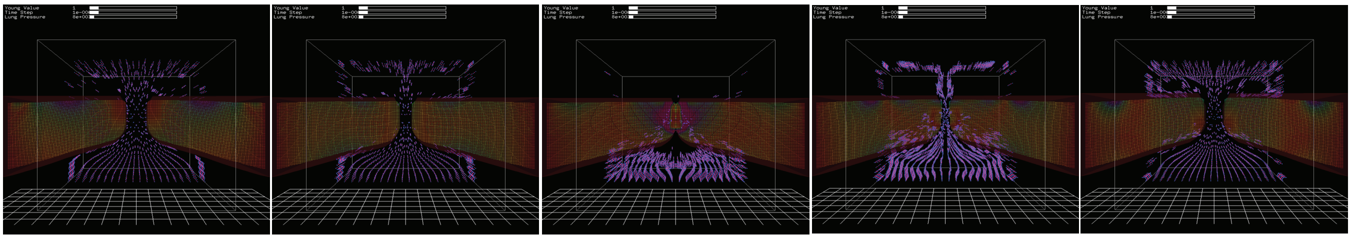

1 Introduction

The glottal wave is the sound source for voiced speech of human. It is generated by the vibration of both vocal folds. The generation process is a complex coupled dynamics between vocal folds which is elastic solid and glottal airflow which is fluid flow. During phonation, vocal folds deforms largely and also both folds collide with each other, and according to their vibratory motion, the glottal flow channel also deforms dynamically and even be closed. Futhermore, glottal flow has a high Reynolds number. Therefore, it can be said this is one example of the most difficult multiphysics problem.

In this work, to simulate the process of glottal wave generation directly, vocal folds are modeled as an anisotropic elastic body including the viscosity friction and its equations of motion are discretalized by MPS(Moving Particles Semi-Implicit) Method on the basis of a Lagrangian formulation, and glottal airflow is modeled as compressible and thermal fluid and its governing equations are discretalized by FDLB(Finite Difference Lattice Boltzmann) Method on the basis of an Eularian formulation, which can simulate directly the fluid dynamic sounds, and both methods are then coupled. To perform the simulation on a usual PC at an interactive rate, most of these calculation is implemented on GPU by Shader(NVIDIA cg, GLSL, and NVIDIA CUDA) and in addition, on CPU side simultaneously in parallel efficiently using OS-dependent thread function and OpenMP.

2 The Contributions of This Sketch

(a): I propose FDLB-MPS coupling Method and applly it to the direct simulation of the process of glottal wave generation in 2D.
(b): In MPS Method, I present the formulation of an anisotropic elastics, and it is implemented on GPU using CUDA efficiently.
(d): In FDLB Method, I simulated glottal flow as compressible and thermal fluid, allowing the direct simulation of fluid dynamic sounds. I also expand Mei et al.'s boundary treatment [Mei 2000] and apply it to this model.
(e): The complex dynamics coupled between elastic solid, that deforms largely, and fluid flow, that has a high Reynolds number, are successfully simulated.
(f): Futhermore, I implemented these method on GPU and CPU simultaneously in parallel, and achieved an amazing framerate: that is, the computational speed increased more than 400 times.

3 Method Overview

Elastics : The MPS(Moving Particles Semi-Implicit) Method is a comparatively up-to-date particle-based method developed for the analysis of incompressible fluids originally by [Koshizuka 1996]. Later, this method was expanded for the problem of isotropic elastics by [Song 2005]. We expand this method for an anisotropic elastics just like the real materials and apply it to represent the motion of the vocal fold tissues.

Fluid : As regards the glottal airflow, we use the compressible and thermal fluid model of FDLBM(Finite Difference Lattice Boltzmann Mehod)-D2Q21Model. We introduce [Tsutahara 2007]'s additional negative viscosity term to simulate high Reynolds number flow, and use the second-order-accurate Runge-Kutta scheme for time marching, the third-order-accurate upwinding scheme for spatial derivation of the lattice BGK equation.

Interaction : The fluid dynamics of the glottal flow is influenced by the presence of vocal folds, and in turn, vocal folds is diriven by air(Fluid)-induced force. My approch to solve this problem is coupling of both FDLB and MPS methods. We define surface particles of the MPS as the particles located along the surface of the vocal fold geometry, and then, define surface of vocal folds by connecting adjacent particles near order by the straight line. This surface becomes the interface between FDLBM and MPSM regime. To handle complex moving and curved boundaries in fluid regime, we apply [Mei 2000]'s method to compressible and thermal FDLBM by adding a few modifications, in which the boundary does not necessarily lies on the lattice nodes, and can deform during the simulation. On the other hand, to calculate the force of the fluid acting on a MPS surface particle, we consider two separate sets of forces, those arising from hydrostatic pressure and those arising from dynamic forces due to fluid momentum. The total force acting on the surface particle are obtained by distributing linearly these fluid pressure forces multiplied by the surface area. To obtain the value of each parameter at an arbitrary point of the surface, the two-dimensional Lagrangian interpolated polynomials formed by the Eularian mesh points are used. By adding those forces to surface particles as external forces, surface particles are updated at each time step.

Implementation : In this work, the calculation of MPS method is implemented on GPU using NVIDIA CUDA(Computed Unified Device Architecture). On the other hand, the calculation of FDLBM is implemented on GPU by NVIDIA cg to use the voxelization techniques, and to pass the data to CUDA regime, PBO(Pixel Buffer Object) are used. To create boundary voxel, we used the dynamic boudary generation method proposed by [Wei 2003], that uses depth peeling techniques. In addition, collision detection and its force calculation of MPS particles is implemented on CPU side simultaneously in parallel with GPU side using OS-dependent thread function, Windows-Thread here. Futhermore, these calculation are parallelized by OpenMP.

4 Results and Conclusion

To perform the simulation, about 30000 MPS particles for the vocal folds and 25000 regular FDLBM meshes for the glottal flow ware used. As the results of rendering to the computer screen once for every 10 calculation loops on a usual PC, the framerate of about 60 frames per sec was obtained. It indicate that the value of each physical parameter can be changed during the simulation interactively. Though a strict bench-mark has not been performed, the computational speed increased more than about 400 times the speed that is attainable by using CPU alone. Moreover, the results of the simulation are in good agreement with previous studies.

In this work, a flexible method is successfully constructed for the simulation of complex coupled dynamics, i.e., the process of glottal wave generation of human, between the elastic body, which entails a large deformation, and fluid flow, which has a high Reynolds number. In addition, fluid-induced sound generation is successfully simulated. Futhermore, by implementating the method on GPU and on CPU simultaneously in parallel efficiently, the numerical calculation was excuted at an interactive rate using a usual PC.

References

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