Fast Volume Preservation for Realistic Muscle Deformation

Min Hong [*] Sunhwa Jung [♦] Min-Hyung Choi [†] Samuel Welch [‡]
University of Colorado at Denver and Health Sciences Center

1. Introduction

Fast and robust volume preservation is essential to achieve the realistic simulation of human muscle structure because approximately 75% of the human body is water and the overall volume is well maintained even during a large deformation. The precise control of the incompressibility is also important to accurately represent the behavior of a muscle such as an anisotropic bulging, and the local non-linear deformation of tissue incurred by skin-to-skin contact. Previously [Nedel and Thalmann 1998] modeled a mass-spring muscle with additional angular springs to preserve muscle shape, but their approach is based on a simplified volume calculation and therefore does not guarantee accurate volume preservation and can alter the material properties due to the additional artificial springs. Unlike a fluid-filled balloon that preserves volume globally, human tissue often demonstrates nonlinear local deformation. This paper presents an efficient volume preservation technique that provides not only robust volume preservation but an ability to control the distribution of volume depending on the material properties and the characteristics of external loadings.

2. Method

We use a simple mass-spring system where discrete mass points are connected by springs to propagate energy. Since a spring only defines the connectivity between two nodes and their relative displacement when the external forces are applied, the mass spring system does not include any volumetric information both at an element and an object level. To overcome the inherent drawback of volume loss of a conventional mass-spring system, we propose a real-time volume preservation method by enforcing a volume constraint at an object level. A common approach to maintain the volume of an object is to preserve the local volume of every element (typically a tetrahedron) at each iteration. It may preserve the volume of an object collectively, but it requires a relatively big linear system solution and may include a singularity problem when internal elements are overly squeezed. Since the size of the linear system is proportional to the number of elements of an object, generally it is difficult to achieve real-time performance.

Our volume preservation method maintains the global volume of a closed mesh structure. The task is nicely divided into computing the overall object volume from a set of surface nodes and triangles, and enforcing the constant volume constraint at every time step of a mass-spring simulation. The surface of a deformable object should be closed to provide the complete boundary of the object but there is no restriction on the convexity or topological configuration. We use the Divergence Theorem to represent the relationship between triple integrals over the volume of a deformable object and a surface integral over the surface of the object. The numerical technique to enforce the constant volume condition is based on the implicit constraint method [Hong et al. 2005]. Since this approach involves enforcing a single volume constraint ($\Phi = V_0 - V = 0$), it is quite fast and robust. Here V_0 is an original volume and V is current volume of object. The constraint force is added into the momentum equation ODE's (Ordinary Differential Equations) to maintain the volume preservation constraint. [Promayon et al. 1996] also applied the Divergence Theorem to compute and maintain the constant volume using the projection method. However, their method requires solving a third order equation to maintain the constraint volume. Moreover, it may not guarantee the physically correct behavior, similar to the post-stabilization method [Cline and Pai 2003] since finding the projection vector to minimize the constraint drift is performed independently from the conforming dynamic motion of the object. Moreover, this method cannot generate the local deformation of object.

Simply maintaining the overall volume may produce undesirable behaviors of deformation since the volume preserving condition can be evenly distributed over the entire surface, showing a balloon like behavior. To address this issue and promote local deformation, the weight vector which is the sum of the volume preserving control terms is introduced. We automatically generate a propagation contour that diffuses the distribution of the effects of the volume preservation on the surface node based on the magnitude, direction, and duration of external load and the bending and sheer properties of the material. Although the final constraint satisfaction may be slightly compromised to achieve the controllability and redistribution of local or global incompressibility, our experiments confirm that the effect is negligible.

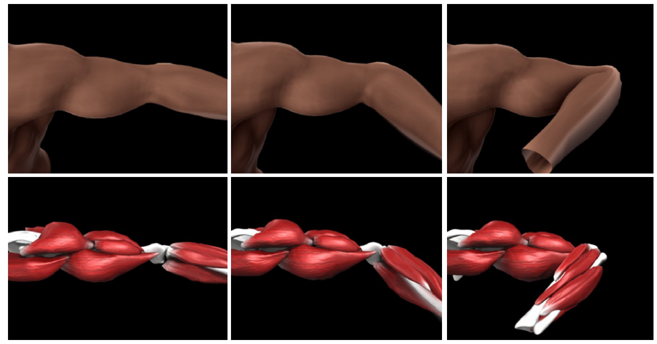

Figure 1: Simulated muscle deformation with proposed volume preservation

References

NEDEL, L. P., AND THALMANN, D., Real Time Muscle Deformations using Mass-spring Systems, *Proceedings of the Computer Graphics International 1998.*

PROMAYON, E., BACONNIER, P., AND PUECH, C., Physically-based Deformations Constrained in Displacements and Volume, *Computer Graphics Forum (Proc. of Eurographics '96)*.

CLINE, M. B., AND PAI, D. K. Post-stabilization for Rigid Body Simulation with Contact and Constraints, *Proceedings of the IEEE International Conference on Robotics and Automation*, 2003.

HONG, M., CHOI, M. H., JUNG, S., WELCH S., AND TRAPP, J., Effective Constrained Dynamic Simulation using Implicit Constraint Enforcement. *Proceedings of IEEE International Conference on Robotics and Automation 2005.*

[*] e-mail: Min.Hong@uchsc.edu
[♦] e-mail: sjung@ouray.cudenver.edu
[†] e-mail: Min-Hyung.Choi@cudenver.edu
[‡] e-mail: Sam.Welch@cudenver.edu