Simulation of Biological Tissues using Numerical Hyperelasticity and Strain-Enriched Finite Element Analysis (Sefea)

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Abstract

In this paper, we present our most recent progress using Strain-Enriched Finite Element Analysis (Sefea) technology [1] in combination with a unique numerical hyperelasticity formulation.

Finite Element Analysis (FEA) simulation has been utilized in many fields to help product design, improvement, and forensic failure simulation. FEA is also the most suitable approach for biomedical applications, as it can handle irregular geometry and anisotropic material behavior. One of FEA's applications is simulating complex deformation of biological tissues and studying the interactions during their deformation and motion. Understanding the mechanics of the behavior of these biological tissues is crucial because it is a prerequisite before any effective treatments can be developed.

However, traditional FEA technologies have difficulty analyzing soft materials because such materials are usually modeled as incompressible/compressible hyperelastic material exhibiting numerical instability when subjected to large deformations. Much research has been conducted on simulating complex deformable soft materials and a variety of new methods or particular treatments have been presented.

Traditionally, hyperelastic materials are defined by strain energy density functions and require analytical differentiation of the energy density function to calculate stress and tangent tensors of hyperelastic materials. When it comes to more complex anisotropic or orthotropic behaviors, the complexity grows exponentially, and it becomes much harder to extract meaningful controlling coefficients for experimental correlation. Due to these issues, we formulated the numerical differentiation for these stresses and tensors directly from the strain energy density functions that are usually readily available from the experimental force-length relationships for wider applications, specifically in biomechanical tissue analysis.

The enriched Sefea method in AMPS has much more accurate local functional space support than traditional FEA and provides a smoother and better estimate of strain across the elements. Using Sefea formulation and the numerical hyperelastic incompressible material implementation, we can reliably simulate human tissue and muscle subjected to large deformation and rotation with accuracy and stability.

Application cases based on muscle and soft tissue mechanical properties from the literature [2, 3] are presented as examples of tissue study. These modeled cases match the observed real-world behavior and demonstrate simulation stability and functionality, suggesting that enriched Sefea is ideal for biomedical applications.

Keywords: Hyperelastic; Finite Element Analysis; Mooney-Rivlin; Large deformation.

Reference

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