Accepted Manuscript

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PII: S0045-7825(18)30157-9
DOI: https://doi.org/10.1016/j.cma.2018.03.033
Reference: CMA 11839

To appear in: *Comput. Methods Appl. Mech. Engrg.*

Received date : 16 December 2017
Revised date : 16 March 2018
Accepted date : 25 March 2018

On improving the numerical convergence of highly nonlinear elasticity problems

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Abstract

Finite elasticity problems commonly include material and geometric nonlinearities and are solved using various numerical methods. However, for highly nonlinear problems, achieving convergence is relatively difficult and loads are restricted to small load step sizes. In this work, we present a new method to transform the discretized governing equations so that the transformed problem has significantly reduced nonlinearity and, therefore, Newton solvers exhibit improved convergence properties. We study exponential-type nonlinearity in soft tissues and geometric nonlinearity in compression, and propose novel formulations for the two problems. We test the new formulations in several numerical examples and show significant reduction in iterations required for convergence, especially at large load steps. Notably, the proposed formulation is capable of yielding convergent solution even when 10 to 100 times larger load steps are applied. The proposed framework is generic and can be applied to other types of nonlinearities as well.

Keywords: Nonlinear elasticity, Newton's method, Nonlinear preconditioning, Compression, Soft tissues, Exponential-type constitutive model, Solver convergence

1. Introduction

With the advance of computational techniques, nonlinearities are becoming increasingly commonplace in mechanical models of solids. In finite elasticity problems, these nonlinearities can arise from different sources: material, geometry, and boundary conditions. Analytical solutions are rarely obtainable for nonlinear problems, making numerical solutions a necessity. Gradient-based methods are commonly used to numerically solve nonlinear problems, where, irrespective of the nature or degree of nonlinearity, the governing equations are linearized to obtain a Newton- or quasi-Newton-based iterative algorithm for finding the solution. For nonlinear problems, the

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