Real time surgical simulation using a lattice-continuum approach

Implementation and validation

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Some words about me

► PhD at University of Grenoble (November 2013)

  *Multiscale approach of concrete structure failure*

► Postdoc at 3SR laboratory (2014)

  *Segmentation of cracks in concrete structure*

► Arrived in Strasbourg (September 2014)
Context

► Surgery: complex practice
  ► Experiences of surgeons
  ► A number of risks
Context

► Computer-based simulation
  ► Surgical training
  ► Guidance
  ► Surgical robotics

► Challenges: cutting, tearing, needle insertion, ...
  ► Topological changes
  ► Contacts
  ► Microstructure of the tissue (discontinuities, holes, )

Courtecuisse et al, 2013
Objectives

► Development of numerical tool
  ► Real-time simulation
  ► Multi-domain: continuum-lattice approach
  ► Multiscale: macro, mesoscopic scale (material scale)

▲ Computational gains
▲ Increase the quality of the cut

► The algorithm is implemented into SOFA framework
Lattice approach

▲ Discrete model: suitable for discontinuity problems
▲ Simplicity to incorporate fracture, cutting
▲ Modeling of material heterogeneity

Discretization by 1D elements

○ Beam element
○ Truss element

▼ Computational cost

HP Bui, University of Strasbourg
Continuum-lattice approach
Continuum-lattice approach

\[ \mathbf{u}_j^L = \mathbf{N} \cdot \mathbf{u}_c^F = N_c(x_j) \cdot u_c, \quad \forall j = \{1, 2, \ldots, n_L\} \]
Continuum-lattice approach

Constraint-based solution

Courtecuisse et al, 2013
Duriez et al, 2006

FEM

\[ A_1 x_1 = b_1 + h H_1^T \lambda \]

LEM

\[ A_2 x_2 = b_2 + h H_2^T \lambda \]

Interface

With Lagrange multiplier \( \lambda \) such that

\[ u^L_j = N \cdot u^F_c \]

Step 1: Free motions \( x_1^{\text{free}}, x_2^{\text{free}} \)

A \( x = b \) with \( \lambda = 0 \)

Step 2: Corrective motions \( x_1^{\text{cor}}, x_2^{\text{cor}} \)

A \( x = h H \lambda \) with \( b = 0 \)

Step 3: Apply correction

\( x = x^{\text{free}} + x^{\text{cor}} \)

Asynchronous preconditioner using sparse LDL^T factorization
Validation tests
Validation tests: 3D tensile test

Analytical solution

\[ u(x) = \int \frac{F}{EA} \, dx = \frac{F}{EA} x \]
Validation tests: 3D tensile test
Validation tests: 3D bending test

Analytical solution

\[ v(x) = \frac{-Fx^2}{6EI} (3L - x) \]
Bending test: FEM approach

\[ \|e\|_{L^2} < C h^{(p+1)} \]
Bending test: FEM-LEM approach
Fracture application

Failure due to tearing
Dynamically Topological Changes

macro zone

coarse node

meso-meso interface
Dynamically Topological Changes
Conclusions & Perspectives

Conclusions

😊 Continuum-lattice coupling is valid

😊 Fracture simulation

Perspectives

😊 Dynamic topological changes

😊 Cutting of soft tissue

😊 Implementation on GPUs
Conclusion & Perspectives

Outlook

► A paper on SOFA implementation with validation tests
► A paper on fracture results
► A paper on real-time cutting
Thank you very much for your kind attention