Simulation of Deforming Elastic Solids in Contact

http://www.cs.unc.edu/~us/fem/

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In the simulation of human and animal bodies, complicated mechanical contact between nonlinearly viscoelastic tissues imposes a challenging numerical problem. The definition of the reaction forces that act on the interface (contact forces) is the key for designing a reliable contact handling algorithm. Traditional methods pay little attention to the continuity of contact forces as a function of deformation, which leads to a poor convergence characteristic. The convergence problem becomes especially serious in simulation scenarios that involve complicated self-contacting surfaces such as folding skin.

We introduce a novel penalty finite element formulation based on the concept of material depth, the distance between a particle inside an object and the object's boundary in a reference configuration. By linearly interpolating pre-computed material depths at node points of a finite element mesh, contact forces can be analytically integrated over contacting regions without raising computational cost. The continuity achieved by this formulation enables an efficient and reliable solution of the nonlinear system. This algorithm is implemented as a part of our implicit finite element program for dynamic, quasistatic and static analysis of nonlinear viscoelastic solids. High nonlinearity and anisotropy typically observed for biological materials are also supported.

Toward Automatic, Realistic Human Motion from 3D Scans

To demonstrate the effectiveness of our method, we simulated flexion of a human knee joint. A finite element leg model with 40,000 tetrahedral elements was built based on the Visible Human Male (Fig. 1). Most of the boundaries between the various components are treated as frictionless interfaces.

Various material parameters are assigned to tetrahedral elements in order to approximate the mechanical properties of different tissues. The femur is fixed in space. The cross section of the thigh is constrained on the cutting plane. The tibia is rotated 150-degree around an axis in the knee joint.

As shown in figures 2-5, realistic effects such as skin fold and sliding contacts of tissues were obtained. To our knowledge, this is the first demonstrated simulation of large-scale motion of a complex model derived from the widely used Visible Human dataset and encompassing multiple tissue types including bone, muscle, tendons, and skin

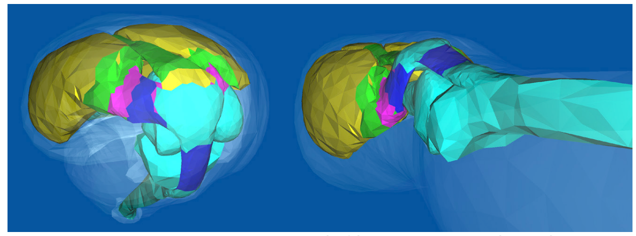

Fig. 2. Knee in bent position (left) and stretched (initial) position (right). Note that the patella slides over the head of the femur.

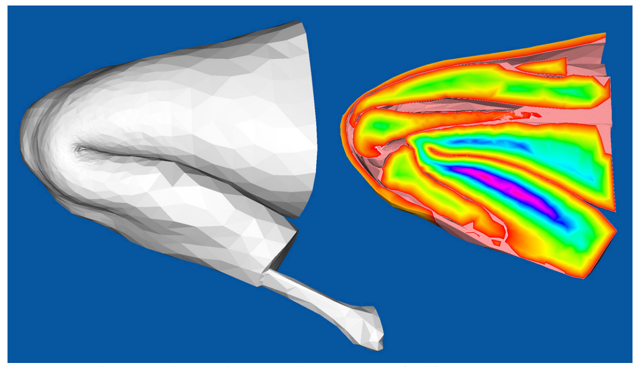

Fig. 3. Skin surface of highly flexed knee (left), cut-away view of the same flexed knee (right). Only parts of the tibia and femur are visible in the cut-away since they are partly in front or behind the cutting plane. Note natural looking sliding contact between skin areas, skin and bones/muscles, patella and femur. The complex self-contact of folding skin was handled without revealing visible penetration. Pseudocolor encodes the value of material depth.

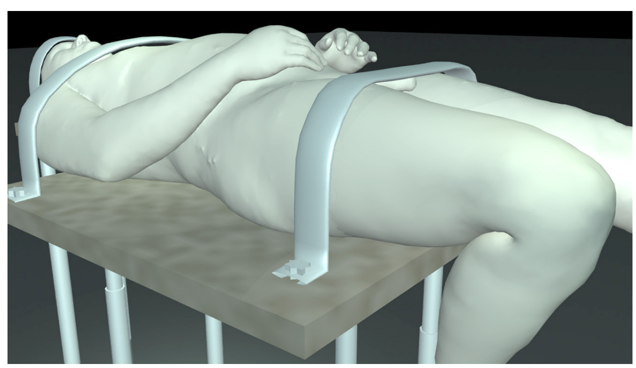

Fig. 4. Visible Human dataset with flexed knee.

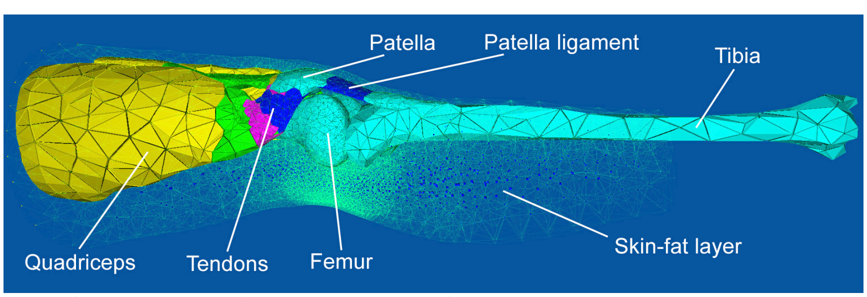

Fig. 1. Constituent parts of the leg model derived from the Visible Human dataset.

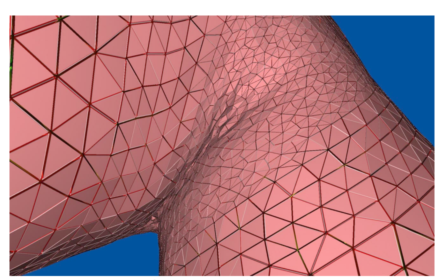

Fig. 5. Close-up of the knee, illustrating the shape of skin folds.