Real-time Patient Specific Surgical Simulation using Corotational Cut Finite Element Method: Application to Needle Insertion Simulation

Huu Phuoc Bui[1,2], Satyendra Tomar[2], Franz Chouly[1], Alexei Lozinski[1], and Stéphane P.A. Bordas[2]

[1]University of Franche-Comté, [2]University of Luxembourg

We present the Corotational Cut Finite Element Method for real-time surgical simulation. Users only need to provide a background mesh which is not necessarily conforming to the boundaries/interfaces of the simulated object. The details of the latter, represented by its surface or/and its internal interfaces, which can be directly obtained from binary images, are taken into account by a multilevel subelement embedding algorithm applied to elements of the background mesh that are cut by the surface/interfaces. To stabilize the system matrix when elements are cut by the surface/interfaces with very small intersections, we propose to move the background node(s) of the concerned cut elements by a distance proportional to the element size. This approach is simple but it can avoid the stability issues in such situations. Moreover, this approach does not include additional parameters as, e.g. ghost penalty method [1]. Dirichlet boundary conditions can be implicitly imposed on the surface using Lagrange multipliers, whereas traction or Neumann boundary conditions, which is/are applied on parts of the surface, can be distributed to the background nodes using shape functions. The implementation is verified by convergence studies with optimal rates. To verify the reliability of the method, it is applied to various needle insertion simulations (e.g. for biopsy or brachytherapy) into brain and liver models while considering frictional interactions between the needle and the tissue. Numerical results show that the present method can make the discretization independent from geometric description, and it can avoid the complexity of mesh generation of complex geometries while retaining the accuracy of the standard Finite Element Method. The proposed methodology is very suitable for real-time and patient specific simulations as it improves the simulation accuracy by automatically, and properly, taking the geometry of the simulated object into account.

References

[1] E. Burman *et al.*, *Int J Numer Meth Engg*, vol. 104, no. 7, pp. 472–501, 2015.