Massively parallel simulation and adaptive mesh refinement for 3D elastostatics contact mechanics problems

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ABSTRACT

The numerical simulation of contact mechanics problems is computationally challenging, as these problems are locally highly non-linear and non-regular. Efficient numerical solutions of such problems usually rely on adaptive mesh refinement (AMR). Even if efficient parallelizations of standard AMR techniques as h-adaptive methods begin to appear [1], their combination with contact mechanics problems remains a challenging task. Indeed, current developments on algorithms for contact mechanics problems are focusing either on non-parallelized new adaptive mesh refinement methods [2] or on parallelization methods for uniform refinement meshes [3,4].

The purpose of this work is to introduce a High Performance Computing strategy for solving 3D contact elastostatics problems with AMR on hexahedral elements. The contact is treated by a node-to-node algorithm with a penalization technique in order to deal with primal variables only. Therefore, this algorithm presents the advantages of well modelling the studied phenomenon while not increasing the number of unknowns and not modifying the formulation in an intrusive manner. Concerning the AMR strategy, we rely on a non-conforming h-adaptive refinement solution. This method has already shown to be well scalable [1,7]. Regarding the detection of the refinement zones, a Zienkiewicz-Zhu (ZZ) type error estimator is used to select the elements to be refined through a local detection criterion [5]. In addition, a geometric-based stopping criterion is applied in order to automatically stop the refinement process, even in case of local singularities. This combined strategy has recently proven its efficiency [6].

In this contribution, we endeavor to extend the combination of these contact mechanics and AMR strategies to a parallel framework. In order to carry out simulations, we place ourselves in the MFEM software [7] environment, an open-source finite elements method library. The proposed scalable contact algorithm is first based on a mesh elements partitioning that guarantees the contact paired nodes to be on the same processors. Furthermore, the contact stiffness matrix is locally built. The combined AMR-contact algorithm is ruled by two nested iterative loops. The external loop concerns the AMR process while the internal one deals with the contact solution. The penalized contact problem is solved thanks to a penalty constrained solver. The iterative contact solution process is performed until the set of active contact nodes (detected by interpenetration) does not vary. Once the contact loop converged, the AMR strategy is locally applied and the mesh decomposition is rebalanced with the previously discussed partitioning contact constraints. Finally, the external iterative process ends once the AMR stopping criterion is satisfied. To perform the AMR on MFEM, the currently implemented h-adaptive method is enriched with our own detection and stopping criteria.

Our AMR-contact strategy is evaluated on 3D academic contact problems with millions up to billions of unknowns. Our HPC approach turns out to be well scalable for hundreds of cores. In addition, with the employed AMR strategy, an optimal mesh, reducing the number of unknowns by at least ten compared to an equivalent uniformly refined mesh, is found in few AMR iterations.

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