ABSTRACT

Lindsay, Payton, Ph.D., Purdue University, August 2017. Coupling Peridynamics with Finite Elements for Fast, Stable and Accurate Simulations of Crack Propagation. Major Professors: Arun Prakash.

While FE methods are computationally very efficient, they are fraught with issues such as mesh dependent solutions, ill-conditioning, slow convergence under large deformations, and limitations associated with the underlying material fracture models. An alternative to a classical solid mechanics approach is the non-local continuum theory of peridynamics (PD), which is better suited for problems involving fracture and fragmentation. However, PD is computationally very intensive, and so in general it is not feasible to simulate large problems with PD without the use of a very powerful workstation.

One method to reduce computational costs is to use domain decomposition (DD) to break down large domains in space. This approach, when used in conjunction with the multi-time-step (MTS) method, enables the decoupling of the temporal scales of each subdomain as well, which gives rise to significant savings in computational cost.

A critical consideration with MTS methods is maintaining the stability and accuracy of the solution. In this research, an error analysis of the MTS method is conducted to ensure convergence of the coupled solution. Analytical error measures for the MTS solution are presented using the truncated Taylor series approach. These results rigorously prove, for the first time, that the MTS method retains the convergence rate of the underlying Newmark method.

One limitation of the state of the art of MTS methods is that most implementations are limited to two subdomains. While this is a convenient simplification for theory and implementation, it places a hard limit on the amount of savings that can be achieved using a MTS approach. Thus, a generalized MTS implementation is presented which enables any number of subdomains to be coupled together, and addresses some of the issues with the existing approaches to couple multiple MTS subdomains.

As mentioned above, PD is a good choice for modeling crack initiation and propagation. However, the computational costs can be prohibitively expensive. Thus, the DD and MTS approaches previously used in classical solid mechanics are investigated for

coupling multiple PD domains as well. In addition to several numerical studies, the theoretical computational cost, convergence, and accuracy of this new method are also investigated.

The final goal of this research is the development of a new MTS approach which leverages the strengths of both the PD and FE methods. This is acomplished by first dividing the problem domain into FE and PD subdomains using DD, and then allowing the subdomains to be integrated with different time steps using MTS. This approach allows one to use PD with a small time step for subdomains within regions of interest, such as critical regions containing crack-tips, and use FE methods with large time steps for the remainder of the problem domain to keep the total computational cost low.