

Abstract

Understanding the behaviour of physical systems through numerical simulations is central to modern science and engineering. While classical continuum mechanics, typically solved using mesh-based numerical methods, has led to significant advancements, it faces limitations in scenarios involving discontinuities such as fractures, phenomena like strain localisation, and large deformations. These challenges have motivated the development of nonlocal or generalised continuum theories and mesh-free numerical methods as suitable alternatives. This thesis investigates fundamental challenges in the mesh-free methods Smoothed Particle Hydrodynamics (SPH), which is well suited for large deformation simulations; and Peridynamics (PD), an inherently nonlocal formulation—and proposes enhancements.

The first part of the thesis addresses the long-standing tensile instability problem in SPH. A novel adaptive strategy is proposed, wherein a B-spline basis—defined over a modifiable knot vector—is employed as the SPH kernel function. The kernel shape is dynamically adjusted to prevent the conditions that lead to instability. The adaptive strategy is initially applied to elastic dynamic simulations, where internal knots are adjusted based on density. Subsequently, the method is extended to fluid problems, where significant particle rearrangement may occur without substantial density changes. In such cases, the knots are adjusted based on particle movement within the influence domain to mitigate instability during large relative deformations. Dispersion analyses guide the adaptive strategies, and the approach’s stability, accuracy, and computational efficiency are demonstrated through benchmark simulations.

The second part of the thesis begins by investigating the role of the inherent length scale in Peridynamics and demonstrates—via wave propagation analysis—that, contrary to several claims, it should not be considered a characteristic length scale capable of regularising strain localisation. Two enhancements are proposed: the incorporation of a nonlocal plasticity model and the superimposition of a local elastic model onto the nonlocal PD formulation. Both introduce

a characteristic length scale, enabling grid-independent simulation of finite-width localisation bands. Leveraging PD’s inherent ability to simulate discontinuities, this framework enables a seamless transition from localisation bands to discrete fractures. Further, a Johnson–Cook material model with nonlocal damage is implemented in an axisymmetric PD framework to simulate plugging failure under blunt projectile impact. A constitutive update strategy for the nonlocal model is developed and validated through dispersion analysis and one-dimensional tests. The added length scale eliminates grid sensitivity and accurately captures plugging failure, enabling the prediction of ballistic limits across a range of target thicknesses.

Finally, the thesis introduces a coupled SPH–PD framework for simulating fluid–structure interaction. A repulsive-force-based coupling strategy is adopted to prevent particle interpenetration, and the framework’s accuracy is validated using representative problems.

Keywords: Smoothed Particle Hydrodynamics, tensile instability, Peridynamics, nonlocal methods, dispersion analysis, length scales, ballistic impact, plugging failure.