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Particles - bridging the gap between solids and fluids

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Abstract

Meshless particle methods, a group of simulation approaches that gains attention in the recent years in engineering and physics, are in the focus of this article. By means of application examples from different engineering contexts, we demonstrate how such methods, especially smoothed particle hydrodynamics and the discrete element method can be used as valuable numerical simulation tools, e.g., in design processes. We provide a simulation example from rock mechanics that demonstrates how the breakage of granite material can be simulated using an enhanced discrete element method approach. The simulation of very soft granular matter based on deformable tetrahedral particle elements, as it might be useful for the simulation of e.g. silicon materials, is another example that emphasizes the flexibility of particle methods. Moreover, we show how cutting processes may be investigated using a smoothed particle hydrodynamic based simulation approach for elasto-plastic solids. Finally, we provide examples for the application of smoothed particle hydrodynamic fluid-multibody simulations to co-simulate sloshing processes.

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1. Introduction

Mesh-based simulation techniques are well established in contemporary computational engineering. Yet there are certain types of processes, many of those actually, where typical continuum approaches fail or are not sufficiently flexible. In some cases, the simulated matter consists of disjoint parts that remain disjoint throughout the entire simulation, e.g. in granular flows. In other cases, when matter is separated into pieces, as it is the case in cutting processes, the initial continuum gradually becomes discontinuous during the simulation. Matter may also undergo permanent separation and rejoining such as in tank sloshing processes. In many of these scenarios in solid and fluid mechanics most of the traditional ways of modeling that involve grid based approaches are not feasible. Permanent remeshing and surface tracking would be inevitable which would result in highly degraded accuracy. This lack of accuracy could only be remedied by spending a high

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computational expense – not to mention the difficulties with handling millions of contacts between bodies by means of a mesh based approach.

Meshless particle methods, an apparently quite new group of methods, on the other hand are very well suited to deal not only with discontinuities and complex boundary conditions but also with most other of the aforementioned issues. But are these methods actually new? The fact is, many meshless particle methods were developed back in the seventies when the available computing power was only sufficient to simulate a restricted number of particles which was insufficient for most real life applications. That is why some of these methods were almost forgotten in the meantime. Fortunately, some of them were continued to be developed almost in silent for decades by groups of enthusiasts.

It turns out that only few of the seemingly fashionable meshless methods are actually new. Due to the tremendous growth of computing power, numerical simulations have become an accepted predictive tool in most industries. While engineers permanently conquer new fields of application some of them critically check their tools once in a while and look around for better ones. In the course of reevaluating tools some of the ancient particle methods were dug out, revived, and sometimes applied in a completely new fashion. An example for such a method is smoothed particle hydrodynamics (SPH). Today a major tool for predicting sloshing flows, the method was initially developed in astrophysics to simulate crashing galaxies.

The general approach of most meshless particle methods resembles: a set of individual particles is simulated whose dynamic motion is influenced by an interchange of momentum. As there is no lasting, i.e. time coherent structure such as a simulation grid, the momentum or more generally speaking, the information interchange between particles may not follow an a-priori known pattern. Some methods, including those presented in this paper, rely on short range particle interactions, hence it is sufficient to know which particles are adjacent. This requires a dynamic detection of particle neighborhoods to determine which particles interchange information. This neighborhood search, an important part of the particle interaction detection, is a key feature of this type of methods. It consumes a major percentage of the computing time, especially in highly dynamic simulations, where it has to be carried out frequently as particle adjacencies change rapidly. On the other hand, transient particle interactions are crucial for the general possibility to simulate material separation. Once the current information interchange pattern between particles has been established via the neighborhood search, different kinds of physical quantities are exchanged, such as momentum or heat. The type of quantities to be exchanged depends on the actual particle method. The particle information interchange is carried out in every simulation step of the dynamic simulation. It yields the input for the last process step that is common to most particle methods, the time evolution of certain variables, such as particle position and velocity. This last step is equivalent to solving the dynamic equations of motion of the individual particles by means of numerical time integration.

Although, there are many similarities between different meshless particle methods, there are also major differences when it comes to the foundation of the various methods. The discrete element method (DEM) that was initially designed for the simulation of granular media, treats particles as individual parts of material with a finite geometrical extension. A particle can represent a granule, a pebble, a rock, or something else. The information interchange often consists of an interchange of momentum during particle-particle contact. It is then crucial to detect the exact surface contact conditions between particles as accurately as possible for being able to compute elastic and viscous repulsive forces normal to the region of contact as well as tangential friction forces. The more precise the shape of the simulated particles is considered in the numerical simulation, the more accurate results can be expected. However, it is obvious that a more complex shape is prone to cause a higher computational expense when it comes to contact detection. In a simulation the shape of the simulated particles may be arbitrarily chosen – a feature that is exploited to minimize the computational expense for contact detection. When millions of particles are to be simulated, it is quite common to use spherical particles in the numerical model even though the real material consists of more complex shapes. The error induced by the often drastically simplified geometry is compensated by means of adjusting certain contact parameters, such as friction or damping parameters, in a way that the overall behavior of the granular system resembles the one of the physical system.

The SPH method, in contrast to the DEM, is based on a continuum model. The governing equations of the respective continuum, e.g. the Navier–Stokes equations for fluids or the partial differential equations of elastodynamics, are solved approximately in their weak form. Thereby, the particles do not represent a