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Bipenalty Method for Stable Time Integration Algorithms in Computational Physics

Jack Hetherington[1], Antonio Rodriguez-Ferran[2], Harm Askes[1],
[1]*Department of Civil and Structural Engineering, University of Sheffield, United Kingdom*
[2]*Laboratori de Calcul Numeric, Universitat Politecnica de Catalunya, Barcelona, Spain*

Abstract

In many areas of engineering and science, computer simulations are used for analysis and design. If the time dimension is relevant, time integration algorithms become an important ingredient of the numerical simulation software. The most popular time integrator is the so-called "explicit time integration" algorithm, which is simple to formulate and straightforward to implement. The main drawback of explicit time integration is its conditional stability: the time increment must be chosen smaller than a certain critical time increment, otherwise the numerical simulation becomes unstable.

This is particularly relevant in case penalty methods are used. Penalty methods are a particular technique to impose constraints to a system of algebraic equations. Although they are very simple to implement, they do tend to change the local physics of the model, thereby affecting the wave propagation speed of the material and thus the critical time step.

A new development is the so-called bipenalty method, in which multiple penalised constraints are added to the system of equations such that the wave propagation speed is preserved. It can thus be shown that there are no adverse effects on the critical time step, which greatly simplifies the application of explicit time integration algorithms. This will be illustrated for elasto-dynamics, in which we will apply penalties simultaneously to the mass properties and the stiffness properties of the system.

Keywords: Computer Modelling; Critical Time Step; Penalty Method; Simulation; Time Integration