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Research Interests

- B.S. thesis argument: Boundary Element Method (BEM) applied to Helmholtz wave problems. The Numerical Analysis unit of the University of Parma has experience on some topics connected to the application of Galerking BEM. The aim of the activity carried out during the redaction of my B.S. thesis was to extend some results already well-established for the Laplace equation in integral form to the case of Helmholtz equation using some new quadrature schemes for weakly singular and Cauchy principal value integrals suitable for h-, p- and h-p versions of Galerking BEM technique.
  Moreover these practice turned out to be useful also in PhD research that considered the Galerking BEM applied to transient wave equation.

- *2005-2006*: numerical methods for extended kinetic theory.
  The extended kinetic theory deals with rarefied gas dynamics in presence of non-conservative reactions. The main goal of the activity developed in these years was to study kinetic models describing chemical reactions and inelastic scattering between gases with several energetic levels in their internal structures. The particular case analyzed was the one of a reversible chemical reaction governed by the hyperbolic non-linear BGK-equations: Boltzmann-like equations where the collision part is heavier.
  Together with Numerical Analysis and Mathematical Physics units of the University of Parma, I tried to find a numerical strategy to simulate the reactive BGK equations. In particular I focused on problems with axial symmetry, which are of interest in many applications like for instance the classical evaporation-condensation problem. The method I used is based on time splitting techniques, which are widely known in the numerical analysis of the classical Boltzmann equation but their application to kinetic systems describing reacting gas mixtures was not discussed until that moment, to my knowledge.
  The time splitting approach has the advantage of simplifying the problem by treating separately the two steps, the convection or transport step, which solves the free-streaming equations along the characteristic lines, and the collision step, which solves the spatially homogeneous BGK equations. The numerical solution of this latter, which can be regarded as a Cauchy problem, has been evaluated with Runge-Kutta explicit schemes of different order. Some results were obtained on time-dependent Riemann problems for reacting mixtures of four gases and were presented at VIII SIMAI Congress, at the 3rd Summer School on "Methods and models of kinetic theory" and at the closure workshop for the Galileo Project.

- from *2007* up to now: numerical resolution of hyperbolic transient wave equation.
  In 2007 I approached elastic wave propagation problems in multilayered media. In particular I have considered their reformulation in terms of boundary integral equations directly in space-time domain.
  Numerical results have been obtained using an approximation technique based on a particular weak formulation in time-space domain, taking advantage of some properties of the energy of the system related to transient wave problem.
  Thanks to the simple structure of boundary integral equations, it's possible to prove coerciveness and continuity properties of the energetic quadratic form for 1D domains and, as a consequence, the unconditional stability of the numerical schemes. In 2D problems, theoretical results have been achieved in the case of a flat obstacle.
  Numerical results have been obtained using a Galerkin discretization of weak problems. Representing the analytical solution of the integral problem with piecewise polynomial functions in the space-time domain, the applied element by element technique produces a linear system

with a Toeplitz block lower triangular matrix easily solvable with appropriate accuracy without high computational costs.
The implementation of this procedure implies during the calculation of the matrix element a double analytic integration in time variables and then numerical integration of weakly singular, singular and hypersingular double integrals in space variables with several troubles concerning their approximation. Therefore in the thesis I have developed some suitable quadrature techniques in order to achieve satisfactory precision.
The several numerical results obtained are very interesting in comparison with other ones found in literature: instabilities phenomena are never present in the energetic procedure. First results are referred to problems with boundary conditions of Dirichlet, Neumann and mixed type in one-dimensional domains with homogeneous or non-homogeneous transient wave equations. The following ones are referred to the extension of the energetic formulation to two-dimensional problems also in multi-domains configurations modeling wave propagation in materials with different physical characteristics. Some of the obtained results were presented in national and international conferences and at now, we are working to the extension to the 3D case with the future possibility of relevant improvements in BEM-FEM coupling.

- Fast techniques for construction and resolution of Boundary Integral Equations linear systems.
  With the aim to extend the application of the energetic formulation to always more elaborate simulations, at the ECCM 2010 congress in Paris some initial results have been presented, showing the actual reduction of computational costs that can be obtained applying the restriction matrices method to wave propagation problems with geometrical symmetries, without loosing precision. This research project [PR2] (whom I was the supervisor) has been funded by GNCS (an Italian organization devoted to research about scientific computation). At the ECCOMAS 2012 congress, the possibility of extension of this technique to 3D problems has been illustrated, exploiting the Plato Solids congruences also.

- Numerical methods for quantitative finance.
  A growing research topic is the adaptation of numerical techniques well consolidated in physics and engineering to the differential models developed within the Quantitative Finance [PR1]. In particular, it is in development an efficient numerical method for the evaluation of financial options pricing through Heston model (1993) where the change in price volatility of a stock is correlated with the price itself.

Financed Projects

PR1. Research Fellow Program (GNCS-2013): *Integral equations approach for numerical resolution of Quantitative Finance problems;*
coordinatore: Dott.ssa C. Guardasoni.

PR2. Research Fellow Program (GNCS-2010): *Application of Restriction Matrices to Boundary Element Method for evolutionary problems;*
supervisor: C. Guardasoni.

PR3. Research Projet GNCS-2013: *Fast methods for the numerical resolution of systems of integro-differential equations;*
supervisor: Dott.ssa A. Aimi.

PR4. Research Projet GNCS-2012: *Coupling of Numerical Methods for BIEs and PDEs related to external and multi-layers evolutionary problems;*
supervisor: Dott.ssa A. Aimi.

PR5. Progetti di Ricerca GNCS-2011: *Numerical Methods for problems of elastic waves propagation in multi-domains;*
supervisor: Dott.ssa A. Aimi.

PR6. Italian Research Program (PRIN 2009): *Boundary Element Method Method for elastic waves propagation problems;*
supervisor: Prof. M. Diligenti.

PR7. Italian Research Program (PRIN 2007): *Boundary Element Method Method for elastic waves propagation problems;*
supervisor: Prof. M. Diligenti.

PR8. Italian Research Program (PRIN 2007): *Advanced Numerical Methods for evolutionary equations and multi-scale problems;*
supervisor: Prof. G. Naldi.

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