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Houssem Haddar • Ralf Hiptmair • Peter Monk •
Rodolfo Rodríguez

Computational Electromagnetism

Cetraro, Italy 2014

Alfredo Bermúdez de Castro, Alberto Valli
Editors

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Preface

The CIME School on "Computational Electromagnetism" was held in Cetraro (Italy) from June 9 to June 14, 2014.

Numerical approximation of partial differential equations in electromagnetism has attracted more and more attention over the last few decades. On the one hand, new theoretical results about the solutions of Maxwell's equations have been obtained, highlighting some properties useful for more efficient discretizations; on the other hand, innovative numerical schemes have been proposed and analyzed, based on finite elements, boundary elements or finite differences.

In particular, the use of finite elements saw a fundamental change of paradigm about 30 years ago, when it became clear that finite elements with degrees of freedom expressed in terms of edge and face integrals were the most suited for numerical approximation in electromagnetism.

These notes are based on the four courses delivered in Cetraro, and the aim is to present some recent and significative results related to different aspects of numerical simulation of real-life electromagnetic problems, including some more theoretical results that are useful in devising and analyzing the approximation algorithms.

The content of the courses is the following.

Ralf Hiptmair's contribution is concerned with the spatial discretization of Maxwell's equations in a bounded domain by means of edge elements. The presentation covers different aspects: the modeling of electromagnetic problems from the point of view of exterior calculus, starting from the classical Maxwell's equations and arriving to their variational formulation; the introduction of finite element exterior calculus and the construction of discrete differential forms, with the aim of devising suitable Galerkin discretizations of Maxwell's equations; the numerical analysis of the discretized equations in order to establish a priori discretization error estimates, with special emphasis on the Maxwell cavity problem.

The chapter written by Rodolfo Rodríguez deals with the eddy current model in harmonic regime and its numerical approximation by finite element methods. Several formulations are presented: in the first one the unknowns are the magnetic field in conductors and a scalar magnetic potential in dielectrics, with current sources as boundary data; the second one is a saddle-point mixed formulation based

on the magnetic field in the whole domain, and on the electric field in dielectrics; the third one is expressed in terms of a scalar magnetic potential in a part of the dielectric region and of a vector magnetic potential in the complementary part. The stability and convergence properties of the associated finite element schemes are presented.

Peter Monk (together with Jielin Li and Daniel Weile) gives a thorough description of the time domain integral equation method, a major tool in the computational analysis of electromagnetic scattering problems. The presentation is mainly concentrated on the Electric Field Integral Equation, and the issues of convergence and stability are considered in detail, for both spatial and temporal discretization; in particular, an in-depth analysis of Convolution Quadrature techniques for time discretization is presented. As a numerical example, the scattering of electromagnetic waves from perfectly conducting objects is described. The problem of scattering by a homogeneous penetrable body is also analyzed, leading to the introduction of a new boundary integral operator related to the magnetic field.

The final contribution, due to Houssem Haddar, is an overview of the so-called "qualitative" methods for inverse electromagnetic scattering problems. The focus is on the inverse geometrical problem, namely, on recovering the shape of some inclusion from the measurement of scattered electromagnetic waves. An analysis of the linear sampling method, originally proposed by Colton and Kirsch in 1996, and of some more recent variants of it is presented in detail for the full three-dimensional electromagnetic problem. An additional related topic is also addressed: the problem of the existence of transmission eigenvalues (values of the frequency for which the interior transmission problem is not well posed).

It was a pleasure to work with all the lecturers. We would like to thank them for their efforts in presenting these important topics in a clear yet detailed way, and for their contribution to the nice atmosphere that characterized the entire school.

Finally, we would like to thank CIME for having accepted our proposal, for the efficient organization and for having hosted the school in a beautiful location. Special thanks are addressed to GNCS-INdAM and to the Departamento de Matemática Aplicada of the University of Santiago de Compostela for their financial support.

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