Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 108C (2017) 818–827

Procedia Computer Science

International Conference on Computational Science, ICCS 2017, 12-14 June 2017,
Zurich, Switzerland

Higher-Order Finite Element Electromagnetics Code for HPC environments

Daniel Garcia-Donoro[1], Adrian Amor-Martin[2], and Luis E. Garcia-Castillo[2]

[1] Xidian University, Xi'an, China.
daniel@xidian.edu.cn
[2] Department of Signal Theory and Communications, Leganes, Madrid, Spain.
[aamor,luise]@tsc.uc3m.es

Abstract

In this communication, an electromagnetic software developed to work in High-Performance Computing (HPC) environments is presented. The software is mainly based on the Finite Element Method (FEM) making use of a number of numerical techniques developed by its authors including its own family of higher-order curl-conforming elements and a non-standard mesh truncation methodology for the analysis of open region problems such as those of scattering and radiation. The code is written in FORTRAN 2003 and it adopts from scratch parallel programming paradigms such as Message Passing Interface (MPI) and Open Multi-Processing (OpenMP). It also includes an in-house development to ease the use of remote computer systems and HPC environments. Initially designed for single-user multicore machines and small cluster environments, a number of modifications have been included in the code in order to make it capable of running on large-scale computer systems and hence, be able to deal with larger problems in terms of number of unknowns. Details of the implementation are shown. Numerical results obtained on an HPC system corresponding to the analysis of a few illustrative challenging problems are also shown.

Peer-review under responsibility of the scientific committee of the International Conference on Computational Science

Keywords: Finite Element, Electromagnetics, HPC, MPI, OpenMP

---

1 Introduction

In this communication, a simulator that makes use of some of the research developments made within the research group the authors belong to is presented. In the last years a number of electromagnetic simulators have been introduced in the scientific community. The origin of these simulators is, usually, some legacy in-house codes which are constantly developing new features but keeping the same core. For this reason, the efficient use of HPC (high-performance computing) systems is difficult to achieve since many libraries have to be rewritten. Indeed, the simulator presented here, called HOFEM —higher order finite element method— is an in-house

Peer-review under responsibility of the scientific committee of the International Conference on Computational Science
10.1016/j.procs.2017.05.239

Table 1: Formulation magnitudes and parameters

	$\mathbf{V}$	$\bar{\bar{f}}_r$	$\bar{\bar{g}}_r$	h	$\mathbf{P}$	$\mathbf{L}$	Γ_{D}	Γ_{N}
Form. **E**	$\mathbf{E}$	$\bar{\bar{\mu}}_r$	$\bar{\bar{\epsilon}}_r$	η	$\mathbf{J}$	$\mathbf{M}$	Γ_{PEC}	Γ_{PMC}
Form. **H**	$\mathbf{H}$	$\bar{\bar{\epsilon}}_r$	$\bar{\bar{\mu}}_r$	$\frac{1}{\eta}$	$\mathbf{M}$	$-\mathbf{J}$	Γ_{PMC}	Γ_{PEC}

code that has been rewritten from scratch to adopt HPC paradigms such as Message Passing Interface (MPI, [1]) and Open Multi-Processing (OpenMP, [3]).

HOFEM kernel makes use of the Finite Element Method (FEM, see e.g., [12]) due to its versatility: e.g., complex geometries and non-homogeneous media can be characterized easily. In short, this method is based on the subdivision of the physical domain into simple geometrical shapes (tetrahedra, hexahedra, triangular prisms...) over which the solution is approximated by polynomials. Thus, the original partial differential equation can be translated into an algebraic system of equations. The correctness of the solution povided by the kernel has been already verified and validated, [9, 10].

Preliminary performance tests of the simulator were conducted on single-user multicore machines and small cluster environments. Recently, the code has experimented a number of modifications in order to make it capable of running on larger-scale computer systems and hence, be able to deal with larger problems in terms of number of unknowns. In this context, the motivation of this communication is to show the performance of HOFEM in such HPC environments.

The rest of the paper is organized as follows: the FEM formulation and the electromagnetic features of HOFEM are brielfly described in Section 2 , the computational features and flowchart of its execution in parallel are presented in Section 3, numerical results are presented in Section 4, and finally, some conclusions are provided in Section 5.

2 Electromagnetic Modeling Features

HOFEM makes use of a weak formulation based on the double curl vector wave equation to characterize the electromagnetic field in a given problem domain Ω^{FEM}. The formulation is applied in the frequency domain in terms of either electric ($\mathbf{E}$) or magnetic ($\mathbf{H}$) field

$$\boldsymbol{\nabla} \times \left(\bar{\bar{f}}_r^{\,-1}\boldsymbol{\nabla} \times \mathbf{V}\right) - k_0^2\,\bar{\bar{g}}_r\,\mathbf{V} = -jk_0h_0\,\mathbf{P} - \boldsymbol{\nabla} \times \left(\bar{\bar{f}}_r^{\,-1}\mathbf{L}\right) \quad \text{in } \Omega^{\mathrm{FEM}} \tag{1}$$

where k_0 is the wavenumber in vacuum, $\mathbf{V}$ is the unknown field and $\mathbf{P}/\mathbf{L}$ are the impressed electric and/or magnetic currents within Ω^{FEM}. Table 1 shows the different magnitudes involved in the $\mathbf{E}$ and $\mathbf{H}$ formulations.

The boundary conditions considered are of Dirichlet, Neumann and Cauchy types:

$$\hat{\mathbf{n}} \times \mathbf{V} = \boldsymbol{\Psi}_{\mathrm{D}} \quad \text{over } \Gamma_{\mathrm{D}} \tag{2}$$

$$\hat{\mathbf{n}} \times \left(\bar{\bar{f}}_r^{\,-1}\boldsymbol{\nabla} \times \mathbf{V}\right) = \boldsymbol{\Psi}_{\mathrm{N}} \quad \text{over } \Gamma_{\mathrm{N}} \tag{3}$$

$$\hat{\mathbf{n}} \times \left(\bar{\bar{f}}_r^{\,-1}\boldsymbol{\nabla} \times \mathbf{V}\right) + \gamma\,\hat{\mathbf{n}} \times \hat{\mathbf{n}} \times \mathbf{V} = \boldsymbol{\Psi}_{\mathrm{C}} \quad \text{over } \Gamma_{\mathrm{C}} \tag{4}$$

where Γ_{D}, Γ_{N} and Γ_{C} stands for the boundaries where the Dirichlet, Neumann and Cauchy conditions, respectively, apply. Symbol $\hat{\mathbf{n}}$ is the outward unit vector to the considered boundary