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Fast and efficient algorithms for computational electromagnetics on GPU's architecture

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Integral formulations can be more convenient than 3D finite-element-method (FEM) codes for the numerical solution of quasi-magnetostatic (eddy currents) problems in large and complex domains, consisting of many interconnected parts or components (e.g. magnetic confinement fusion devices), since they do not require the discretisation of non-conducting subdomains. A good accuracy is often achieved with a relatively coarse discretization, thus reducing the need of allocated memory and computing time. Moreover, suitable techniques (e.g. the Fast Multiple Method (FMM) [1] or the Adaptive Cross Approximation (ACA) coupled with hierarchical matrix (H -matrix) arithmetics [2]), can be used to overcome the impractical memory and computational time requirements which arise in very large scale models (integral formulations require the storage of dense matrices: the matrix size scales quadratically with the number of degrees of freedom n and its inversion has a computational cost of the order of n3 for both direct and iterative solvers).

However, by following an integral approach, a specific post-processing tool is needed to evaluate the magnetic flux density and the magnetic vector potential components produced in the 3D space by known current density distributions over elementary geometric entities associated to the mesh elements (uniform polyhedral for 3D, or uniform polygonal sources for 2D) or to the sources themselves (2D axisymmetric massive or filamentary coils, 3D coils modeled by means of uniform polyhedral, polygons or current sticks).

Several analytic expressions for the calculation of the magnetic flux density and the magnetic vector potential produced by a polyhedron [3], a polygon [4] or a current stick [5] with a uniform current density have been published by many authors.

The aim of this paper is to present fast and efficient algorithms for the computation of the magnetic field and magnetic vector potential and their implementation on GPU's to benefit from their Single Instruction stream Multiple Data stream (SIMD) architecture, by programming each thread to compute the contribution to the magnetic field (or magnetic vector potential) of a single elementary source at a single field point [6]. A critical review of the results will be presented for some test cases, together with an overview of pros and cons of GPU's vs CPU's implementations. Their applicability in Real Time (RT) applications in fusion technology is also discussed.

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