A Parallel Poisson Solver Library for Accelerator Modeling Applications

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1 Introduction

Particle accelerators play a key role in high energy and nuclear physics studies, and many other applications. Design and operation of those sophisticated and expensive devices require extensively using multi-physics computer simulations. Those multi-physics computer models include space-charge effects, beam-beam effects, electron cloud effects, and other physical effects. In order to simulate the aforementioned effects self-consistently, one has to solve the Poisson equation at each step. A parallel, fast Poisson solver will be critical for the quick return in accelerator modeling applications.

In the accelerator community, a number of fast Poisson solvers were used and developed for accelerator modeling applications [1–24]. Subject to different boundary conditions, those Poisson solvers involve different numerical methods that solve the Poisson’s Equation on a grid. For an open boundary condition, an FFT-based Green’s function method was developed [3–10]. For a closed boundary condition with regular shape, a finite difference spectral method was used [11–15]. For a closed boundary condition with irregular shape, a multigrid finite difference method is often used [16–18, 25].

Besides solving the differential Poisson equation directly, the integral equation method provides a category of alternative solvers based on the integral format. These solvers convert the differential equation into an integral equation
on the boundary. They do not need the grid that covers the whole domain and thus avoid any issues caused by the grid. The fast multipole method [19, 20], which has been implemented in a few accelerator simulation tools [21, 22], can be especially efficient with open boundaries. The integral equation method can also be applied to boundary value problems with any geometry. Finally, we note that some algorithms and codes [23, 24, 26] have been developed by computational mathematicians but have not been transplanted into the accelerator community.

2 Current and future challenges

So far, those Poisson solvers were developed on different computer platforms for accelerator modeling applications. Some of the implementations are serial while others take advantage of parallel architectures. They were also developed using different programming languages, e.g. Fortran, C++, Python or MatLab. There is also no uniform interface for accelerator modelers to use those Poisson solvers conveniently or interchangeably. Furthermore, the parallel Poisson solvers have often not been optimized for good efficiency and scalability on massive parallel computers, and very few have been ported to GPUs.

3 Advances needed to meet challenges

In order to meet the above challenges, we propose to develop a fast, portable, parallel Poisson solver library, which would improve the usage of those fast Poisson solvers and benefit the accelerator modeling applications. Modern programming practices and tools can be leveraged to develop the library that will be portable across CPUs and GPUs, and with standardized interfaces that make it easy for accelerator modelers to use in their applications, toolkits and ecosystem [27, 28]. Multiple levels of parallelism (on-node and multi-nodes) will be supported, with special attention to efficiency and scalability. The library will also include a detailed and up-to-date user documentation, as well as automated test suites and well-benchmarked examples.

References


