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Acceleration method for solving Poisson's equation in particle-in-cell method: investigation on acceleration efficiency and optimal acceleration parameters under different methods

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The particle-in-cell (PIC) method is one of the most widely used plasma dynamics simulation methods[1]. Based on the first principle, the PIC method hardly uses any physical assumptions, which makes it simulate the plasma behavior well. However, the large number of grid nodes and macro particles lead to the slow computational speed of the PIC method, which limits its application prospect. For instance, the time consumed to solve the discretized Poisson's equation at each grid point can account for about half of the total computing time. Pushing particles and collisions will take up the other half of the computing time. Therefore, these processes need to be accelerated through algorithms or by improving computer performance. Currently, there is no comprehensive and quantitative research on various acceleration methods used in the PIC method.

In this paper, various acceleration methods for solving the discretized Poisson's equation in PIC methods are studied, such as the successive overrelaxation iteration (SOR) method, the multigrid (MG) method[2], and the parallel computing method. The convergence order of iteration varies with the relaxation factor, as shown in Fig.1 (b). The optimal relaxation factor for different grid quantities is found. The residual of the SOR method at every node is compared with that of the MG method in Fig.1 (d), which reveals why MG methods converge faster. The convergence order as a function of the relaxation factor and MG level is illustrated in Fig.1 (e). The optimal relaxation factor of the MG method is different from that of the SOR method. The code in this paper is validated by comparing the plasma parameters with the benchmark in ref. [3]. By comparing the acceleration effects of different acceleration methods, this paper provides theoretical support for selecting the optimal calculation parameters for specific calculation conditions.

References

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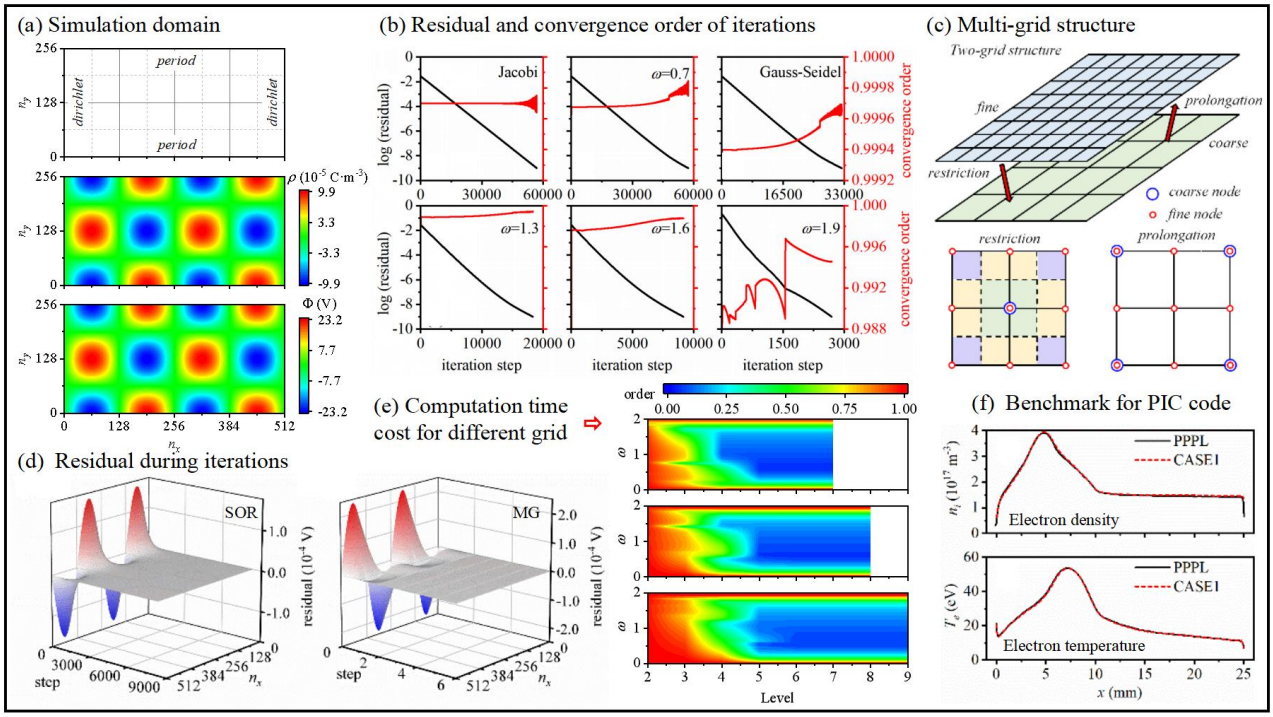

Figure 1. (a) Simulation domain, charge density and potential for Poisson equation, (b) Residual and convergence order during different iterations, (c) Structure of multi-grid method, (d) Residual at every node during different iterations, (e) Computation time cost for different grid node number, (f) Benchmark of the PIC code with the results in ref. [3].