Massively Parallel Method of Moments with a Highly Scalable Direct Solver on Tianhe-2 Supercomputer

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Introduction

Electromagnetic (EM) analysis of large models is of crucial interest in many applications, such as EM safety of airplanes and airborne radars. Due to the high frequency EM fields and waves, accurate solution of these problems is still a challenge.

Along with the latest developments on computer technology, the use of High Performance Computing (HPC) techniques on supercomputers with thousands of terabytes (TB) of memory, can significantly boost the performance of the method of moments (MoM) in extremely large applications.

Scalability

The parallel efficiency of MoM is investigated by the simulation of a airborne array. Figure 3 shows the variation of speedup and parallel efficiency using CPU cores. It is seen from the figure that, the program can achieve the efficiency of higher than 65% when the number of CPU cores increases from 600 to 12000.

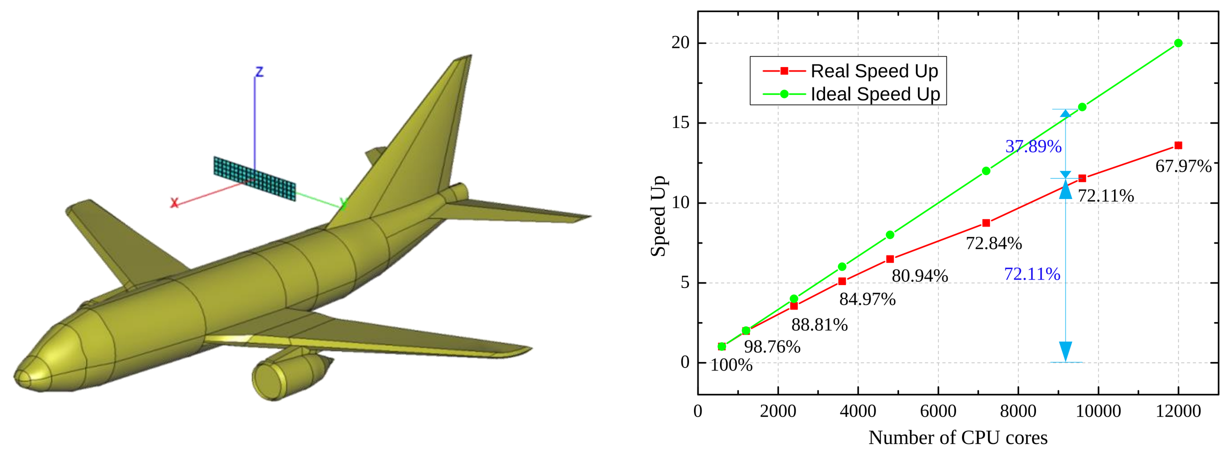


Figure 3. Airborne array model for efficiency test

The parallel scale of MoM is tested by the simulation of an airplane. The parallel MoM solver can use up to 200,000 CPU cores or 390,000 CPU and MIC cores.

The near field of the airplane is simulated using higher-order basis functions, yielding 1,253,200 unknowns, which requires 22.9 TB memory. A total number of 201,600 CPU cores are employed to solve the problem. The solution time is about 50 minutes.

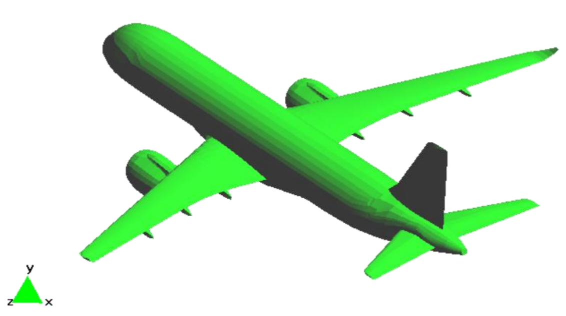


Figure 4. Airplane model for scale test

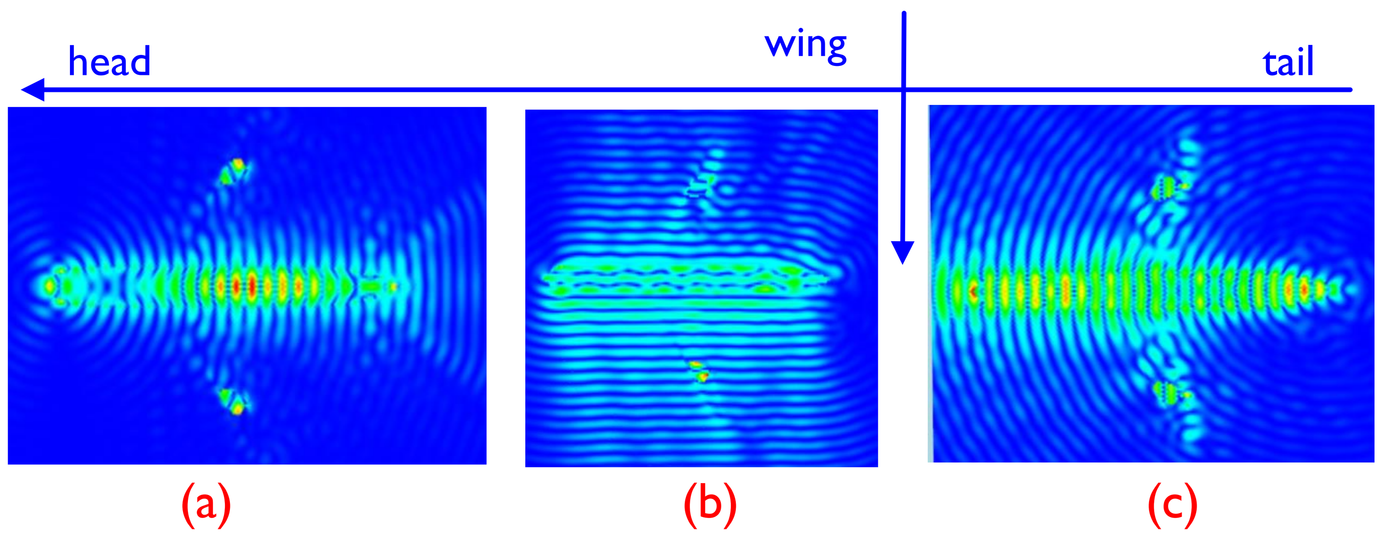


Figure 5. Near field distribution at 1.0GHz, and the plane wave is incident form: (a) head of the airplane, (b) the wing of airplane, (c) the tail of airplane.

The airplane is simulated using MoM with RWG basis functions at 0.2 GHz, generating 357,650 unknowns, which requires 1.86 TB memory. The maximum parallel scale of the proposed algorithm is about 2000 nodes (contains 48000 CPU cores and 342000 MIC cores). The solution time is about 6 minutes.

Parallel MoM with a Direct Solver

The parallel MoM with two types of basis functions, higher-order and RWG basis functions, are developed. The integral equation employed is a general form of the Poggio-Miller-Chang-Harrington-Wu (PMCHW) formulation. When one of the boundary surfaces between the two different regions is PEC, the magnetic currents are equal to zero at the boundary surface and that equation degenerates into the electric field integral equation (EFIE).

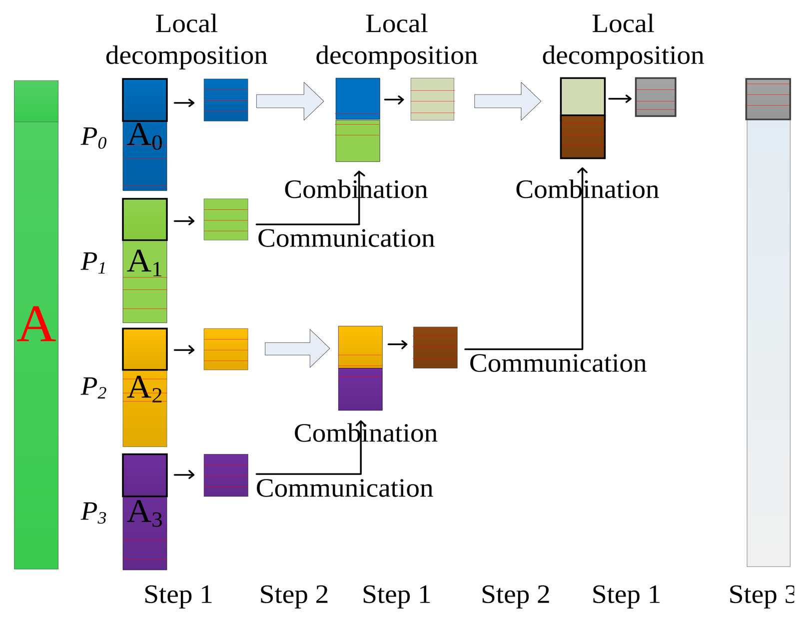


Figure 2. Illustration of parallel pivoting in the proposed parallel LU decomposition solver

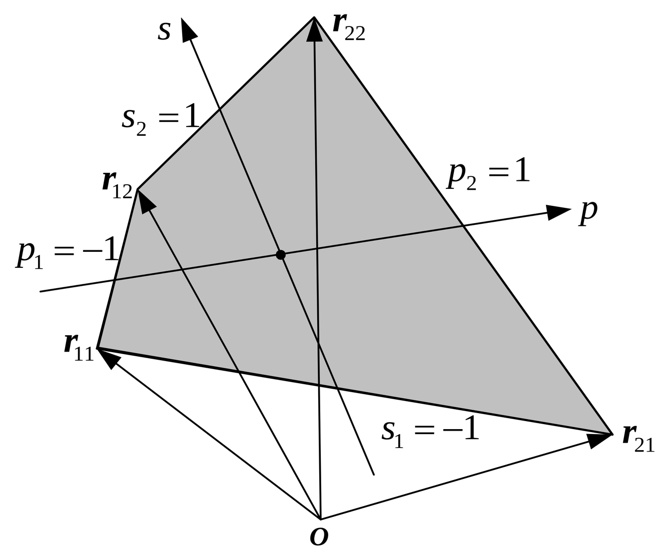


Figure 1. Geometric modeling for higher-order basis functions: a bilinear quadrilateral patch

The major difference between the proposed parallel LU decomposition and the conventional LU algorithm in ScaLapack resides in the parallel pivoting approach. The proposed parallel pivoting is based on a tree-like strategy (Fig. 2), which is able to reduce the number and amount of communication during pivoting, and thus enhance the parallel performance of our direct solver.

Applications

The height of the radome is 1450 mm, and the bottom radius is 300 mm. The antenna array has 200 elements. Parallel higher-order MoM running on 4800 CPU cores is used to simulate the model, which generates 528,275 unknowns. The solution and optimization time is about 5 hours.

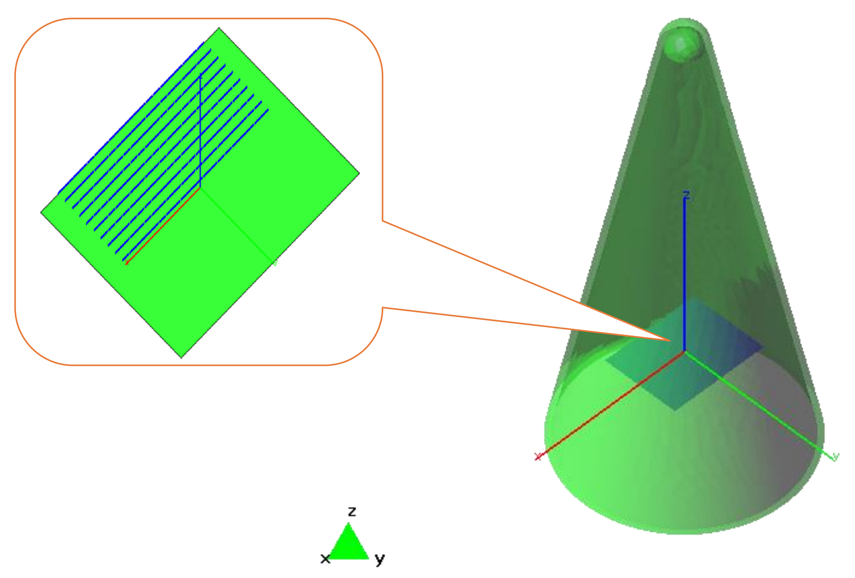
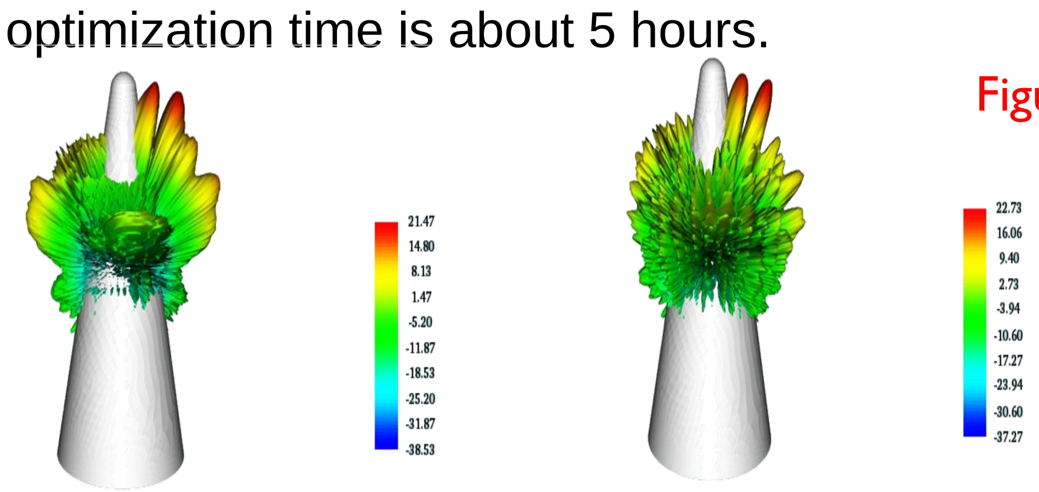


Figure 6. Radome-enclosed antenna array



(a) before optimization (b) after optimization.

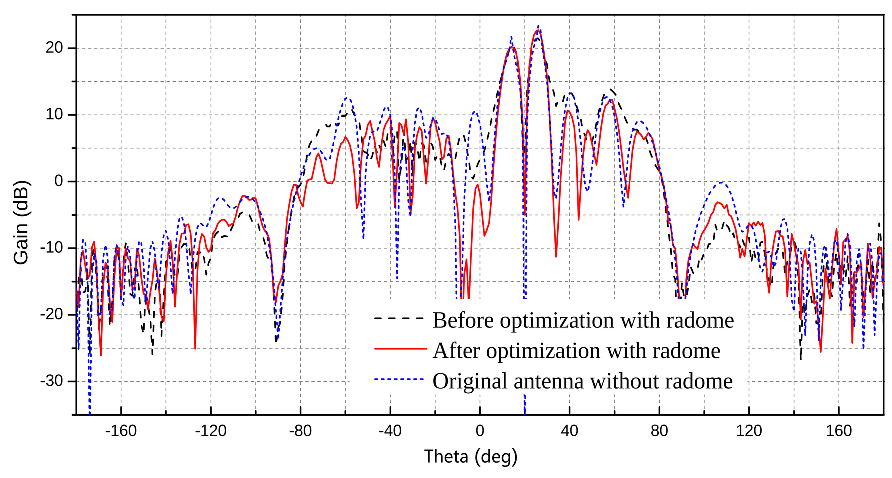


Figure 7. Difference-beam patterns of the radome-enclosed antenna array

It is obvious that, the maximum gain of the radome-enclosed antenna array before optimization is 21.46 dB and the null depth of difference beam is 17.56 dB. Then after optimization the gain is 22.70 dB and the null depth of difference beam is 27.69 dB.

Conclusion

The MoM is a numerically accurate and widely used method in computational electromagnetics. It generates a complex dense linear system after discretizing boundary integral equations using basis functions. The parallel algorithms with two types of basis functions, higher-order and RWG basis functions, are developed, and a highly scalable direct solver based on LU decomposition is designed for both CPU and CPU/MIC on Tianhe-2 Supercomputer, which is one of the world's fastest supercomputers located in Guangzhou. And the parallel MoM solver can use up to 200,000 CPU cores or 390,000 CPU and MIC cores. The scalability is demonstrated by the solution of large linear systems with over one million unknowns arising from real-life electromagnetic applications.