MPI Parallelization of the Level-Set Reconstruction Algorithm

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1. Introduction

The Level-set technique has shown the potential to effectively solve the shape reconstruction problems in recent years [1], [2]. This method is topologically flexible which means that breaking and merging of regions can be handled implicitly. Also, minimum *a priori* information is required in the reconstruction algorithm. However the level-set methods are computationally demanding. For tracking a contour, a two-dimensional function (2D) should be propagated in the whole computational domain and for tracking a surface, a three dimensional function (3D) function should be propagated. Although the narrowband scheme could be employed to save the computation time, the level set method is still computationally demanding. Therefore parallel programming could be employed to solve these problems. Parallel computing has been used in many applications such as weather forecasting, molecular dynamics simulations, computational fluid dynamics, computational electromagnetics, crystal growth etc [3]-[6].

One way to parallelize a sequential code in distributed memory systems is through the message passing interface (MPI). Using the MPI, each processor is executing part of the parallelized code and communicates with the other processors using the message passing [7]. In this work, the sequential code developed in [2] is effectively parallelized using the MPI. All objects are 2D perfect electric conductors (PEC) immersed in air. The illuminating waves are transverse magnetic (*TM*) plane waves where the electric field is parallel to the axes of the cylinders. The objective is to retrieve the number of scattering objects, their shapes and locations in few minutes versus hours using the full-band level set method as reported in [2].All parallelization results are implemented and tested on the San Diego Super Computer Center (SDSC) facilities.

2. Methodology

The relationship for tracking the motion of an interface is known as the Hamilton-Jacobi equation [1]

$$\frac{\partial \phi}{\partial t} + F\left\|\nabla \phi\right\| = 0 \qquad (1.a)$$

$$\phi_0 = \phi(x, y, t = 0) \qquad (1.b)$$

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where F is the normal component of the deformation velocity.
The sequential algorithm is parallelized in three main steps described as follows:

A. Domain Decomposition

The level-set method is a time iterative approach where the solution at each iteration depends on the preceding time step. Therefore the iterative part of the code remains sequential. Each processor will be responsible for updating the level-set function in its assigned domain and processors will communicate with each other the information about border grid points.

B. Deformation velocity

The deformation velocity is a summation of all incident and measurement angles [2]. Therefore, each processor calculates a partial velocity and a partial cost function. The total velocity and the total cost function are calculated using the contributions from all processors.

C. Parallel Matrix inversion

All processors work together to compute the inverse of MOM impedance matrix. The inverse of MOM impedance matrix will be used to find the induced forward and *adjoint* currents [2] on the surface of evolving objects. Standard parallel libraries are employed for this purpose.

3. Numerical Results

The reconstruction of five cylinders with different cross-sections is examined using the parallelized code. The reconstruction begins at low frequency of 100 MHz and increases to 3 GHz. After 14000 iterations, five cylinders are fully reconstructed. The reconstruction results at different iterations are shown in Fig. 1 and the normalized cost function is depicted in Fig. 2.

A maximum speed-up of 108X is achieved, when no optimization is used vs. 54X when optimization is used, as shown in Fig. 3a. The curve labeled "without optimization", shows the speedup using the run-time of the un-optimized sequential code while the curve labeled "with optimization" shows the speedup using the optimized sequential code. The execution time using a single processor is about 4 hours while it is four minutes using 256 processors, both on the Datastar machine using aggressive optimization. The corresponding efficiency is 21% for 256 processors as shown in Fig 3b.

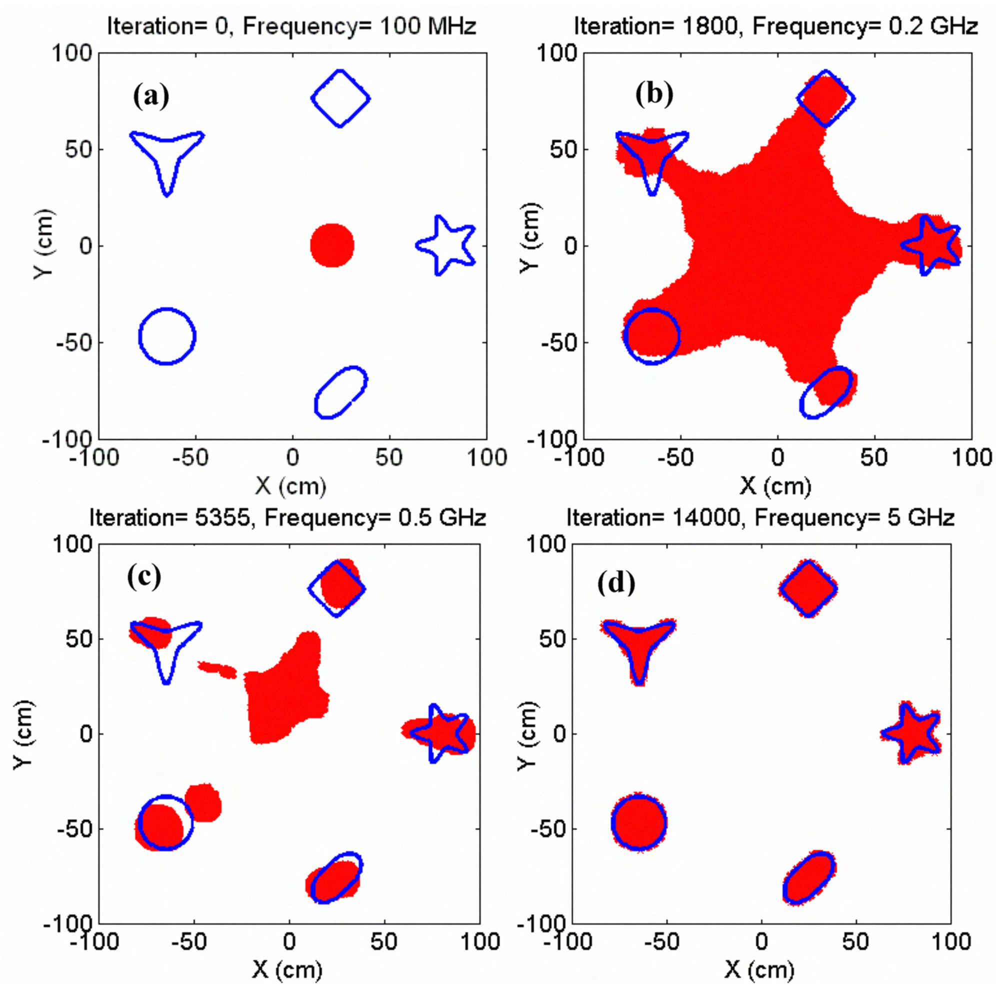

Fig. 1. Reconstruction of five conducting cylinders at different iterations (a) initial guess (b) after 1800 iterations (c) 5355 iterations (d) after 14000 iterations

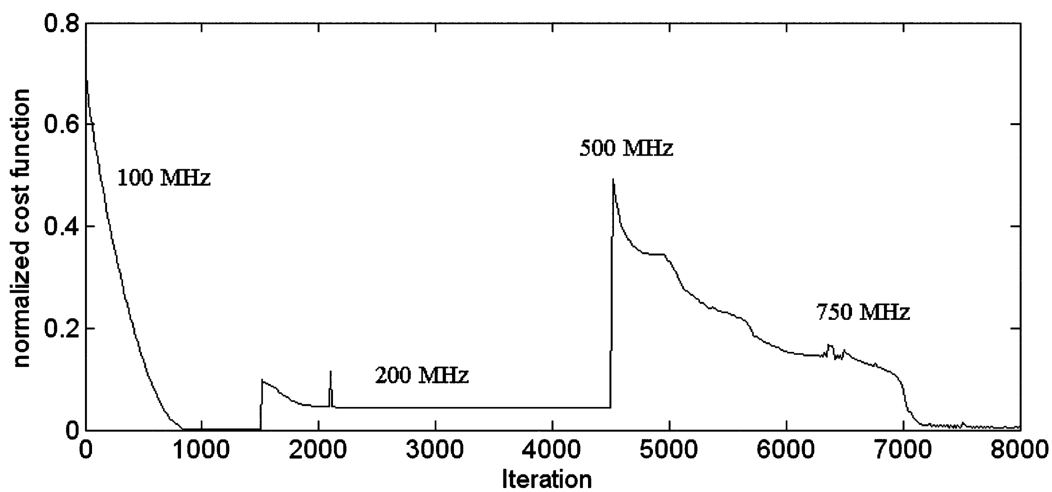

Fig. 2. The normalized cost function of five objects

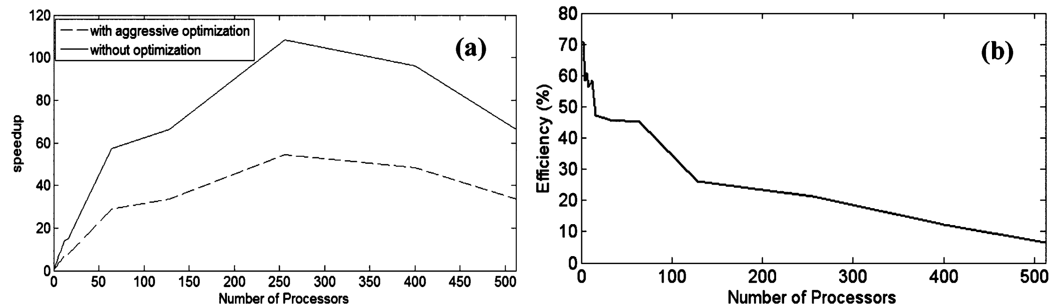

Fig. 3. (a) Speedup, (b) Efficiency versus the number of processors

4. Conclusion

The level-set algorithm is parallelized using the domain decomposition approach, the distribution of calculating the deformation velocity, and the parallelized ScaLAPACK library for inverting the MoM impedance matrix. The numerical results show a speedup of 84X for the reconstruction of the star-shape cylinder, 53X for the reconstruction of the two elliptical cylinders, and 54X for the reconstruction of the five cylinders.

5. Acknowledgements

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