Weighted DDM Enhanced by Fast Algorithm for Scattering from Large Metallic Targets

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Abstract

In this paper, A weighted Domain Decomposition Method (Weighted DDM) enhanced by the hybrid fast algorithm, i.e. the multilevel accelerated Cartesian expansion-multilevel fast multipole algorithm (MLACE-MLFMA), is adopted to analyze the electromagnetic scattering from large metallic targets. In the computational scheme, the surface integral equation (SIE) is adopted and the MLACE-MLFMA is utilized to accelerate the matrix-vector multiplications (MVMs). Compared with the unenhanced weighted DDM, the computational efficiency has been largely improved which can be demonstrated by the numerical results.

Introduction

In the practical simulations, scatterings of the large target are always been considered. However, considering the memory consumption and computational complexity of Method of Moment (MoM), high costs for calculating scatterings of large targets are inevitable. In [1]-[3], significant fast algorithms to accelerate iterations are proposed, which are the multilevel fast multipole algorithm (MLFMA), the multilevel accelerated Cartesian expansion algorithm (MLACEA) and the multilevel accelerated Cartesian expansion-multilevel fast multipole algorithm (MLACE-MLFMA). By applying the MLFMA or MLACE-MLFMA, the memory cost and computational complexity can be reduced. However, preconditioners, resulting in more memory and computation costs, may be needed to improve the convergence of the iterative solution.

To improve the iterative convergence and avoiding extra memory consumption, domain decomposition method (DDM) is proposed and developed. In the DDM, transmission conditions will be constructed to ensure the continuity of current vector between artificial boundary metallic edges. Here, overlapping subdomains [5] or meshed unknowns on artificial edges [6] can be utilized as transition zone. In [5], [6], the Gauss-Seidel-like iterative scheme is utilized to solve the DDM equation.

Recently, a weighted domain decomposition method (weighted DDM) [7] is proposed for scattering problems by using the Surface Integral equation (SIE). In the weighted DDM, the solution process has been divided into three main steps: calculation of subdomain scatterings, solution of the weighted coefficients and judgment of the iterative convergence. Moreover, Far Field Approximation (FFA) [8] is used to accelerate the computation of interactions between subdomains.

Theory

1st step

$$Z_{ii}I_i^k = \begin{cases} V_i & ,k=1 \\ V_i^k & ,k>1 \end{cases}$$

LU decomposition method

2nd step

$$Z \cdot I = V \qquad (1)$$

$$I = \sum_{k=1}^{n}\sum_{i=1}^{M}\beta_{i,k} I_{i,k} \qquad (2)$$

$$\sum_{k=1}^{n}\sum_{i=1}^{M}\beta_{i,k} Z \cdot I_{i,k} = V \qquad (3)$$

In order to claculate $\beta_{i,k}$, $Z \cdot I_{i,k}$ is considered as the test function.

$$Z'_{Mn\times Mn}\beta'_{Mn\times 1} = V'_{Mn\times 1} \qquad (4)$$

$$Z'(ik,ik) = \left(Z \cdot I_{i,k}\right)^{H} \cdot \left(Z \cdot I_{i,k}\right) \qquad (5)$$

$$V'(ik) = \left(Z \cdot I_{i,k}\right)^{H} \cdot V \qquad (6)$$

(4) is solved by the LU decomposition direct solver.

3rd step

$$error(k) = \frac{\left\|V - V^k\right\|_2}{\left\|V\right\|_2}$$

$$V_i^k = V_i - \left(Z \cdot I^{k-1}\right)_i = V_i - \sum_{j=1}^{k-1}\beta_{i,j} Z \cdot I_{i,j}$$

Memory and computational costs

MoM based weighted DDM

Total memory cost :

$$T_{memory}^{total} = p\left(\frac{N}{M}\right)^2 + MnN$$

Total computational cost :

$$T_{operator}^{total} = nN^2 + (Mn)^2 N + M\left(\frac{N}{M}\right)^3 + nM\left(\frac{N}{M}\right)^2 + T_{repeated}$$

The computational cost for calculating mutual-coupling matrices: $T_{repeated}$

MLACE-MLFMA based weighted DDM

Total memory cost :

$$T_{memory}^{total} = N\log N + p\left(\frac{N}{M}\right)^2 + MnN$$

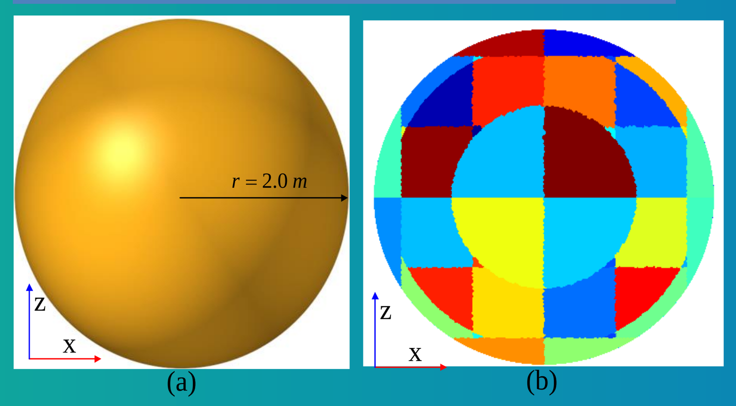
Total computational cost :

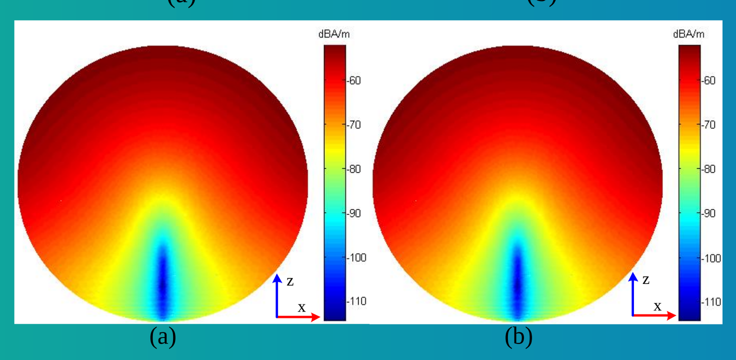
$$T_{operator}^{total} = MnN\log N + (Mn)^2 N + M\left(\frac{N}{M}\right)^3 + nM\left(\frac{N}{M}\right)^2$$

In our work, advantages of the weighted DDM are inherited. Different with the computation of matrix-vector multiplications in [7], [8], the MLACE-MLFMA is adopted here. The effectiveness is demonstrated on the simulation results.

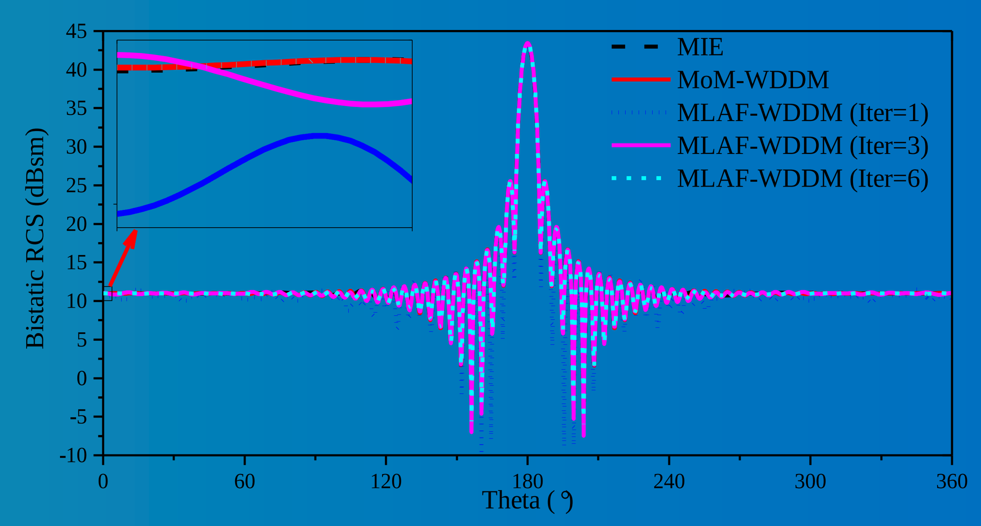
Numerical results

A. Metallic sphere conductor





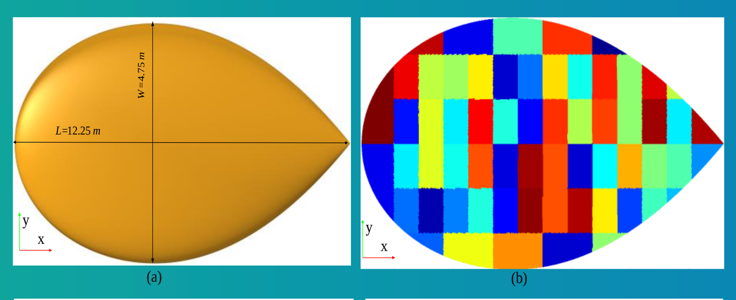
(a) MoM-WDDM; (b) MLAF-WDDM

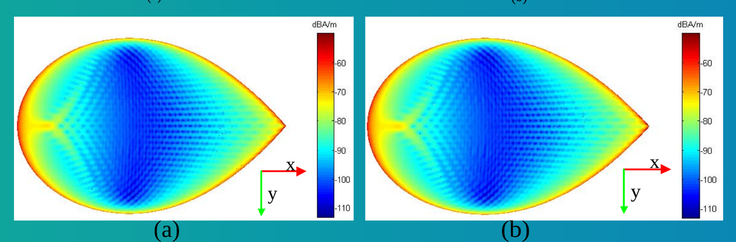


"MLAF"=MLACE-MLFMA

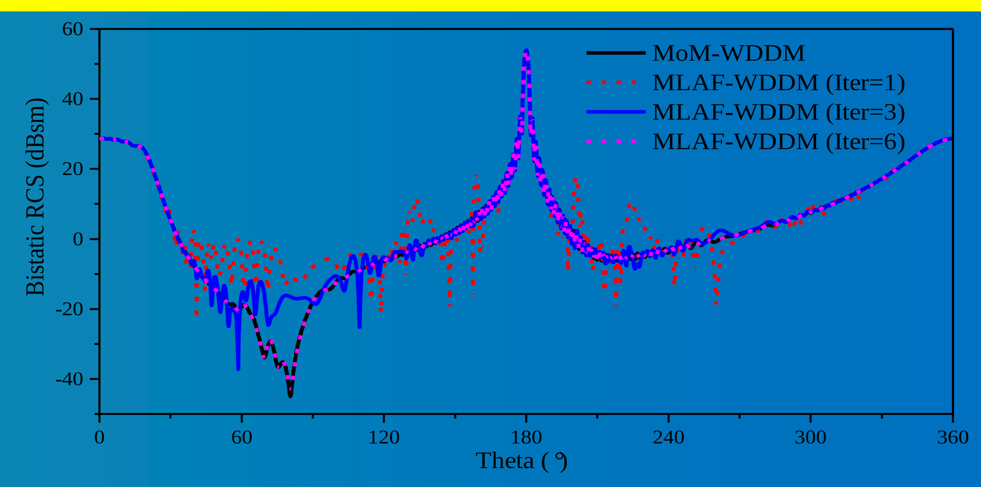
Frequency: 1.0 GHz
Triangles: 99730
Unknowns: 149595
Subdomains: 80

B. NASA almond



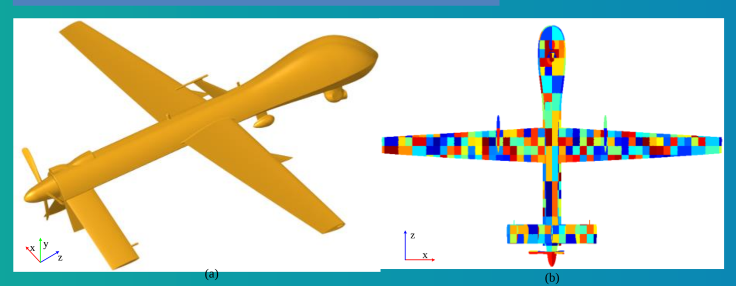


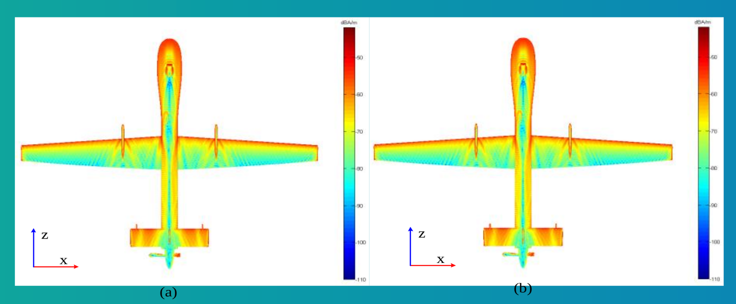
(a) MoM-WDDM; (b) MLAF-WDDM



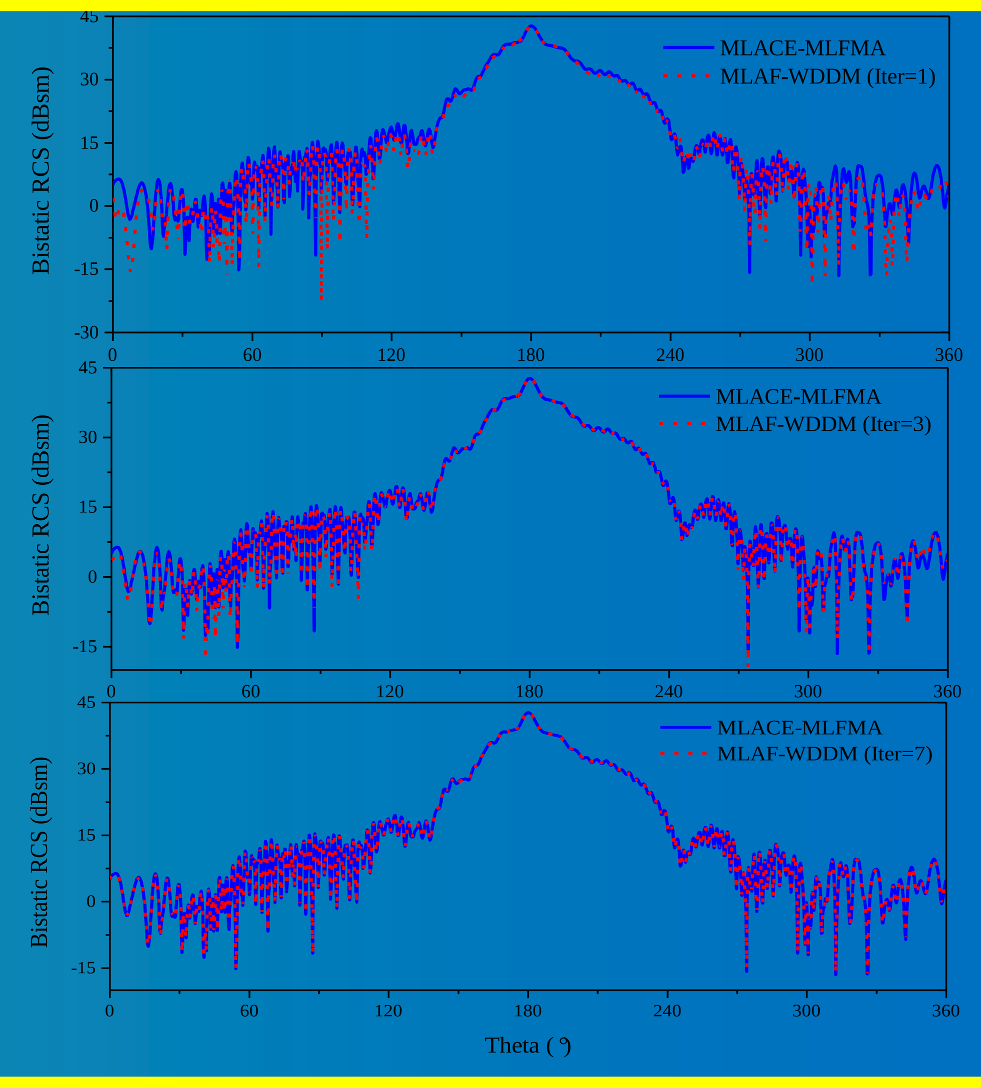
Frequency: 1.0 GHz
Triangles: 210818
Unknowns: 316227
Subdomains: 124

C. Aircraft





(a) MLACE-MLFMA; (b) MLAF-WDDM



Frequency: 2.0 GHz
Triangles: 533418
Unknowns: 800127
Subdomains: 448

Models	Peak memory (GB)		Iterations		Time cost (minutes)	
	MoM-WDDM	MLAF-WDDM	MoM-WDDM	MLAF-WDDM	MoM-WDDM	MLAF-WDDM
Sphere	11.26	13.33	6	6	196.99	16.84
Almond	18.62	22.85	6	6	857.34	36.10
Aircraft	--	38.07	--	7	--	188.30

Conclusion

In our work, the weighted DDM is accelerated by the multilevel accelerated Cartesian expansion-multilevel fast multipole algorithm (MLACE-MLFMA). Here, the MLACE-MLFMA is mainly utilized to accelerate the matrix-vector multiplication. The validity of the accelerated weighted DDM has been demonstrated by the proposed simulations. Compared with the unenhanced weighted DDM, computational efficiency has been highly improved despite of the increase of memory. In addition, the size of the subdomains is not required to be uniform, which increases the domain decomposition flexibility.

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