Electromagnetic Characteristics Optimization Based on Shape Deformation

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***Abstract*—A feasible approach to optimize the characteristics of electromagnetic (EM) objects through shape deformation is proposed. We provide a complete and detailed procedure of the optimization and investigate the shape deformation formulations for some typical EM objects. Numerical results demonstrate the validity and performance of the optimization approach.**

***Keywords*—EM optimization; design sensitivity; shape deformation; the method of moments (MOM)**

I. Introduction

Over the last several decades, some optimization methods have been discussed in the area of electromagnetics [1]–[3]. The purpose of electromagnetic (EM) characteristics optimization is to optimize the design parameters of EM structures to meet the demands such as getting the target impedance of an antenna. In this paper, the design parameters typically describe the structure's geometry.

Plenty of numerical methods can be used in the optimization, typically physical optics (PO) and the method of moments (MoM) [4]. The process of computing the radiation or scattering results of a given object using EM solving methods can be easy, while the optimization of EM characteristics for a given EM target is complicated due to the difficulty of non-linear optimization problems and the complexity in shape deformation of an object.

To solve this problem, a great number of non-linear optimization algorithms have been discussed, including gradient descent method, conjugate gradient method and BFGS method. However, the shape deformation problem has attracted very little attention.

In this paper, a complete and detailed procedure of the optimization approach is presented. For different kinds of geometry of given objects, different shape deformation formulations are proposed.

II. Formulation

A. Procedure of Optimization Process

The optimization problem is associated with a response function which reflects the optimization target. An optimized object can be obtained by optimizing the value of its response function through non-linear solvers. The complete procedure of the optimization in this paper is shown in Fig.1. Some details for the optimization are illustrated as following:

(1) As a robust numerical method with high accuracy, MoM is used as the core EM solving algorithms in this paper.

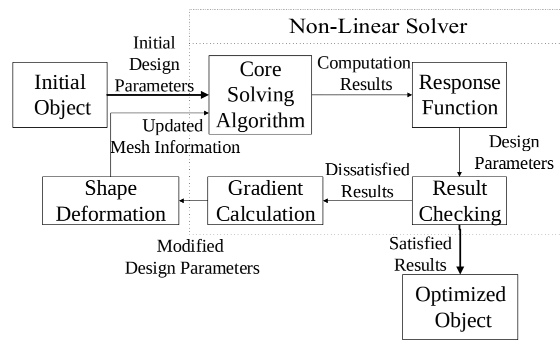


Fig. 1. Procedure of EM characteristics optimization.

(2) The gradient of response function can be calculated by the finite differences method (FDM) [3] or the adjoint-variable method (AVM) [1], [2].

(3) The shape deformation is needed at gradient calculation and iterative process.

B. Basic Equations

In MoM analysis, a linear EM problem is typically represented by

$$Z(x)I{=}V. \tag{1}$$

Here, x is the vector of design parameters, I is the complex currents or current densities, and V is the global excitation vector. The response function is defined as $f(x,\bar{I}(x))$ which has to be differentiable in all its arguments. The target function may have explicit dependence on the design parameters x. It also depends on the solution $\bar{I}(x)$ of (1), and therefore, has an implicit dependence on x.

In the non-linear solver, the design sensitivity represented by the gradient of the response function in the design parameters space $\nabla_x f$ is required.

In this paper, FDM is used to compute the design sensitivity for its simplicity and efficiency.

C. Shape Deformation

The difficulty in shape deformation is how to deform the geometry and mesh based on the modified design parameters at the same time. Now that the geometry of an object will change along with the modification of the mesh points, a shape deformation formulation applied to the mesh points can be used to implement the deformation. In this case, the shape deformation parameters which are associated with design parameters are used to simplify the computation. And the deformation formulation is defined as

$$r_{x,y,z}^{(k+1)} = D(\alpha_1^{(k+1)}, ..., \alpha_n^{(k+1)}, r_x^{(k)}, r_y^{(k)}, r_z^{(k)}) \tag{2}$$

where r is the vector of mesh point and $r_{x,y,z}^{(k)}$ represents the value of the position along different axes at the k-th iteration step, $\alpha_i^{(k)}$ represents the i-th shape deformation parameter which is used to modify the position of mesh points. As a constrained optimization problem, the values of shape deformation parameters range from 0.1 to 10. Notice that for different kinds of target objects, the deformation functions D which will be provided in the next section are different.

III. Numerical Results

To demonstrate the accuracy and efficiency of the optimization approach, some deformation formulations and numerical results are presented. Notice that the models are discretized with triangular facets and the corresponding RWG basis functions [5] are used.

A. Optimization of the Input Impedance of Wire Antenna

To optimize the input impedance of a wire antenna, the response function is defined as

$$f = \left| \frac{Z_{in} - \bar{Z}}{\bar{Z}} \right| \tag{3}$$

where Z_{in} is the input impedance and $\bar{Z} = 70\Omega$ is the target impedance. In this case, there are two shape deformation parameters which are applied to the radius and height of the wire antenna, respectively, and the deformation formulation can be defined as

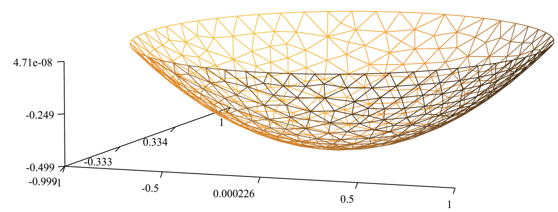
$$D = \begin{cases} r_x^{(k+1)} = {\alpha_1}^{(k+1)} r_x^{(k)} \\ r_y^{(k+1)} = {\alpha_2}^{(k+1)} r_y^{(k)} \\ r_z^{(k+1)} = r_z^{(k)} \end{cases}. \tag{4}$$

The input impedance of the initial wire antenna is (5.10, -912.42) when the frequency is 100 MHz. After the optimization, the output impedance of the wire antenna is (71.77, -0.51), and the optimized shape deformation parameters are $\alpha_1 = 1.28$ and $\alpha_2 = 2.87$, respectively. Furthermore, the value of response function converges after 9 steps of iteration.

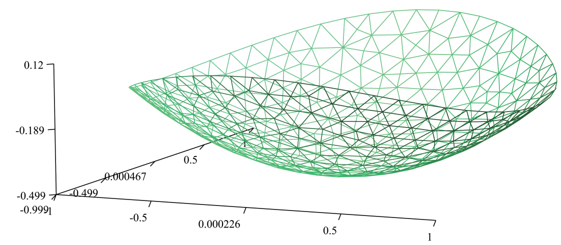
B. Optimization of Radar Cross Section (RCS) Value of Paraboloid

We optimize a paraboloid object to get the target RCS value at the given angle. And the deformation formulation is defined as

$$D = \begin{cases} r_x^{(k+1)} = r_x^{(k)} \\ r_y^{(k+1)} = r_y^{(k)} \\ r_z^{(k+1)} = {\alpha_1}^{(k+1)} (r_x^{(k)})^2 + \\ (1 - {\alpha_1}^{(k+1)})(r_y^{(k)})^2 - 0.5 \end{cases} \tag{5}$$



(a)



(b)

Fig. 2. Initial paraboloid and optimized paraboloid.

where the shape deformation parameter is used to modify the curvature of the paraboloid. For a plane wave whose incident direction is $(\theta = 0, \phi = 0)$ with frequency 300 MHz in VV polarization, our target is to get the minimum RCS value at the given angle $(\theta = 0, \phi = 0)$ in monostatic scattering. The initial paraboloid model is shown in Fig.2(a), and the initial RCS value is 6.74 dBsm. The optimized paraboloid with remarkable deformation is shown in Fig.2(b), and the corresponding optimized RCS value is 3.72 dBsm.

IV. Conclusion

In this paper, a complete and detailed procedure of the electromagnetic characteristics optimization based on shape deformation is proposed. BFGS and FDM are used to implement the optimization. Furthermore, the shape deformation formulation is presented to solve the problem resulting from the modified design parameters. Numerical results verify the feasibility and validity of the optimization approach.

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