Microwave Imaging of Three-Dimensional Malignant Breast Tumors Employing an Enhanced Evolution Strategy

*Payam Rashidi[1], Magda El-Shenawee[1], and Demetrio Macías[2]
[1]Department of Electrical Engineering, University of Arkansas
Fayetteville, AR 72701, USA, Email: prashid@uark.edu
[2]Laboratoire de Nanotechnologie et d'Instrumentation Optique -CNRS FRE 2671
Université de Technologie de Troyes,
12 rue Marie Curie, B.P. 2060,10010 Troyes, France

ABSTRACT

An enhanced optimization technique based on evolution strategies is investigated and applied to the estimation of some unknown parameters that determine the shape and location of malignant breast tumors. The tumor reconstruction is achieved through the minimization of an error function defined between the measured information and the scattered data generated numerically. Our preliminary results show that using Cauchy's distribution in the evolutionary algorithm leads to a significant reduction in the CPU time required to estimate the shape and location of the tumor.

I. INTRODUCTION

Recently, the microwave imaging modality has shown great potential in medical applications, especially in the detection of small malignant breast cancer tumors [1-2]. The significant contrast between the normal and malignant breast tissues at the range of microwave frequencies allows differentiation between these two tissues. The information embedded in the scattered electromagnetic waves (e.g. the electric field) provides information about the electrical properties, shape, and location of the tumor [3]. In practice, it is desirable to develop efficient algorithms that produce tumor images in real time. Therefore studies to improve the CPU time associated with the imaging algorithms are necessary. In previous work [3], we have shown the potential of a standard evolution strategy for the retrieval of the shape and the location of three-dimensional (3-D) dielectric objects immersed in air. In this work, we will extend our study and we will investigate the effect of the application of several methods in the operators of the standard evolutionary algorithm with aim at improving its performance. Particularly, we propose to use Cauchy's distribution instead of the Gaussian distribution in the mutation operator of the evolution strategy [4]. Our preliminary results showed a significant improvement in the speed of the computer code, as will be shown in Section III.

II. METHODOLOGY

An evolution strategy is an iterative optimization technique inspired on Darwin's theory of evolution [5]. This method explores a search space to determine those individuals from a population that provide the optimal solution to the problem studied. The initialization of these individuals is done through a random process. Then, after successive generations, the individuals evolve into fitter points by means of the recombination, mutation, and selection operators. This procedure is repeated until a termination criterion is fulfilled [5]. Very often, the reconstruction techniques based on evolutionary algorithms need further modifications to achieve faster implementations, especially for reconstructing 3-D objects. As it was mentioned before, our attention is focused on the employment of Cauchy's distribution as an alternative to the standard Gaussian distribution [4]. A comparison between these two distributions is shown in Fig. 1. It can be observed that Cauchy's distribution allows the generation of random numbers located farther from the origin than those generated with the Gaussian distribution. This implies that using Cauchy's distribution helps to generate individuals closer to the true values in the search process [4].

III. NUMERICAL RESULTS

The method of moments (MoM) is used to calculate the scattered electric fields from the object. In this work, we will also use the MoM to generate the data from where the unknown parameters will be retrieved. The target 3-D object is discretized into triangular patches with twenty nodes in the ϕ-direction and fifteen nodes in the θ-direction, whereas the reconstructed object is discretized, in each iteration of the evolutionary loop, into ten and five nodes in the ϕ-direction and θ-direction, respectively. Our preliminary results are focused on reconstructing a 3-D dielectric ellipsoid with six unknown parameters to be retrieved. The object is illuminated with s-polarized plane waves at a wavelength λ_0, while the received fields are calculated in the near-zone at synthetic point receivers. The parameters of the target object, associated with its physical shape and the coordinates of its center (i.e. a, b, c, x_0, y_0, z_0), are respectively given by $a = 0.156\lambda_0$, $b = 0.356\lambda_0$, $c = 0.556\lambda_0$, $x_0=4\lambda_0$, $y_0=4\lambda_0$ and $z_0=-0.4\lambda_0$. The dielectric constant of the target ellipsoid is $\varepsilon_r = 5.071 - j0.591$. A total of 2176 point-receivers surrounding the object from all directions is used here. The receivers are positioned at $x = 2.5\lambda_0$, $x = 5.5\lambda_0$, $y = 2.5\lambda_0$, $y = 5.5\lambda_0$, and at $z = -1.68\lambda_0$, with a spacing of $0.1\lambda_0$ between the receivers in the x- and y-directions and $0.12\lambda_0$ in the z-direction.

The convergence of the algorithm is shown in Fig. 2. The solid line represents the algorithm based on Cauchy's distribution, the dotted-line represents the standard evolution strategy based on the Gaussian distribution, and the dashed-line represents the algorithm based on Cauchy's distribution employing a reinforcement learning technique [5]. It is clear that the algorithm based on Cauchy's distribution, with or without the reinforcement technique, provides the fastest convergence in this case. The reconstructions obtained with the algorithms proposed are shown in Figs. 3 and 4.

In these figures, the darker ellipsoid represents the reconstructed object and the lighter ellipsoid represents the target object. It can be observed that the Cauchy-distribution based algorithm retrieves the target after 20 inversion iterations (3.5 CPU hours), which is three times faster than the Gaussian-based algorithm, which required 60 iterations (11 CPU hours). All computations are conducted on HP-ALPHA servers (COMPAQ) of 1GHz processor.

IV. CONCLUSION

The preliminary results presented here demonstrate that replacing the Gaussian distribution in the mutation operator by Cauchy's distribution show almost a three fold increase in the object reconstruction time. Modifications of the selection operator are in progress to improve the speed of the imaging algorithm. The enhanced evolution algorithm will be applied to reconstruct a 3-D malignant tumor embedded in normal breast tissue. The number of point receivers will be realistically reduced.

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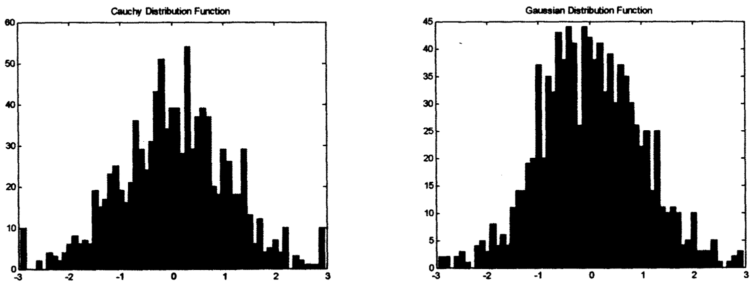

Figure 1 Comparison between the Cauchy distribution and the Gaussian distribution functions

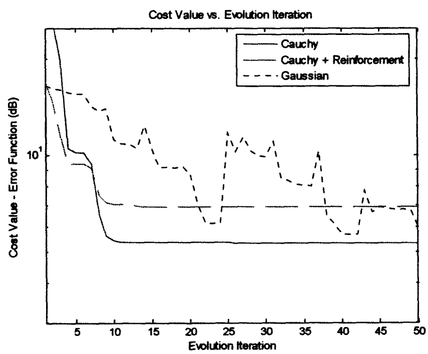

Figure 2 Convergence of the Cauchy, Cauchy-reinforcement-learning and Gaussian based evolution algorithms

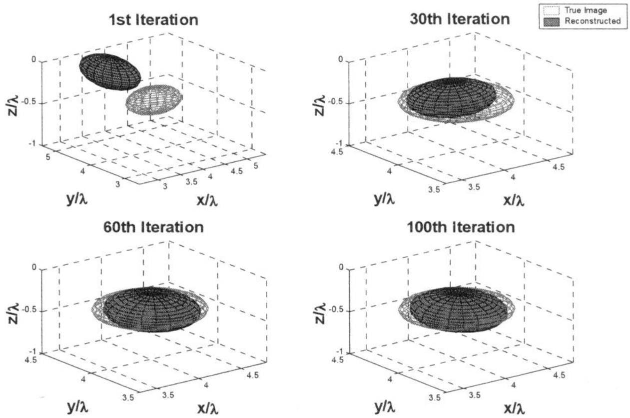

Figure 3 The reconstructed object using the Gaussian-based evolution algorithm

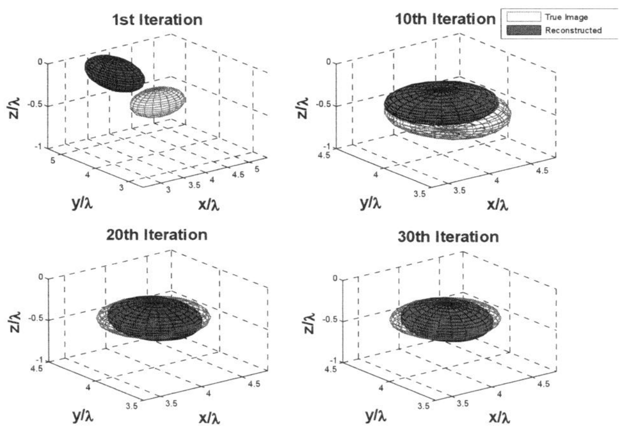

Figure 4 The reconstructed object using the Cauchy-based evolution algorithm