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# Inversion of Scattered Field Using Particle Swarm Optimizer

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***Abstract*— This paper presents multi view to microwave imaging based on contrast source inversion method. Contrast source inversion method recast the inverse problem as an optimization problem. Particle swarm optimizer (PSO) has been used to minimize this cost function and reconstruct the unknown dielectric profile of two dimensional scatterer. The contrast source inversion method recast the inverse problem as an optimization problem in which we seek not only the contrast source but also the contrast itself to minimize a cost functional We perform the inversion of electromagnetic scattered data, measured by Institut Fresnel, Marseile, France, from cylindrical objects for TM illumination. The result shows that the present inversion method enables wide class of scattered field data.**

***Index Terms- Microwave Imaging, Particle Swarm Optimization (PSO) and scattered field***

## I. INTRODUCTION

In recent years microwave imaging techniques have found considerable attention by researcher since these techniques can be used for a number of engineering applications such as biomedical diagnosis of human physiologies [1], [2] non-destructive evaluation [3], [4] subsurface detection [5] and dielectric properties of scaterers [6].

In the inverse scattering modeling, one aims to determine the shape, location and constitutive parameter of the object under investigation from the scattered field. Since the wave field depends upon the materials parameters, the inverse scattering problem is essentially nonlinear. In inverse method the fields and the contrast (permittivity) are considered as fundamental unknown. The cost function consists of superposition the mismatch between the measured field data and the predicted data and the error in satisfying consistency in the interior of the object under investigation. In these relations, an integral operator acts on the contrast source being the product of the unknown field and the unknown contrast (constitutive parameter of the object). Therefore, a more efficient and versatile method has been developed in which the contrast source and contrast are considered as fundamental unknowns. In contrast source inversion method the minimization of two cost function is carried out [7].

Kennedy and Eberhart [8] proposed particle swarm optimization (PSO) technique in 1995, which is a robust stochastic search procedure inspired by the social behavior of insects swarm. The PSO is a multiple-agent optimization procedure in which the individuals, called particles, change their position (state) with time. The particles fly in the multidimensional solution space and adjust their positions according to their own experience and the experience of neighboring particles by exploiting the knowledge of positions encountered by themselves and their neighbor.

## II. MATHEMATICAL FORMULATION

Let us consider a scattering object of an arbitrary cross section. It has been assumed that the unknown scatterer is contained in the investigating domain D as square as shown in Fig.1. The domain D may be chosen large enough to contain the scattering object but larger the size more the computational cost. We assume that the fields vary sinusoidally with frequency ω. We consider that we know the Green function as the fundamental solution in the embedding medium. Spatial points are denoted by p $(x_p,y_p,z_p)$ and $q(x_q,y_q,z_q)$.

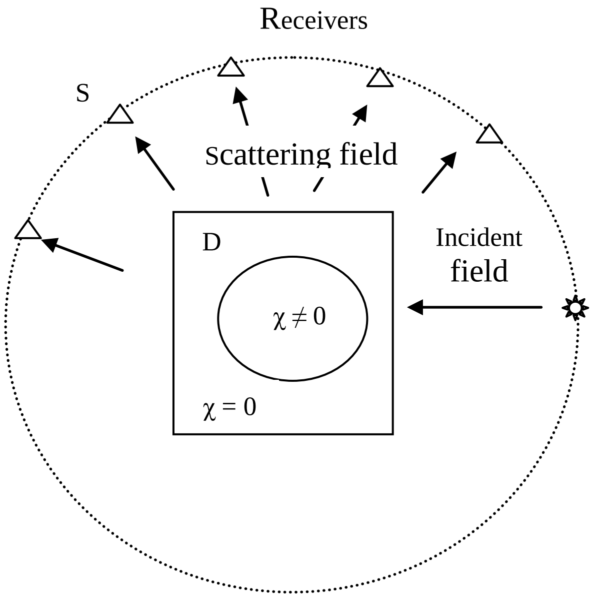



Fig.1 scattering object enclosed in the investigating domain D

The object is irradiated by a number of known incident fields $E_j^{inc}(p)$, j= 1,2,……,J originating from different source positions. For each incident field, total field is denoted by $E_j(p)$ in D and given by equation (1) exterior to D.

$E_j(p) = E_j^{inc}(p) + E_j^{iscat}(p)$ (1)

The scattering fields $E_j^{iscat}(p)$, j=1,2,……..,J is measured on surface S outside the investigating domain D. The total field and the scattered field satisfy the following integral representation in the operator form as

$E_j(p) = E_j^{inc}(p) + G_D \chi E_j$ $p \in D$, (2)

$E_j^{iscat}(p) = G_S \chi E_j$ $p \in S$, (3)

Where χ (q) denotes the contrast of investigating object, so χ (q) = 0 at those points in D outside the actual scattering object. The operators are source type integral representations [9] and represents the field due to a superposition of contrast sources, $w_j = \chi E_j$. They are given by

$G_{S,D} = \int_{q\in D} G(p,q) w_j(q) dv$ $p \in [D, S]$ (4)

where G(p,q) is the fundamental point source solution in the embedding medium, denoted as Green function. The subscript S and D are append to the integral operator G to clarify where in the space the field point p is placed. The forward scattering for (2) and (3) has been solved in [10].

Let the scattered measured on S denoted as $f_j$, then scattered field in (3)is represented as data equation,

$f_j = G_S \chi E_j$ $p \in S$, (5)

We observe that the data equation contains both unknown field and the unknown contrast in the form of product

$w_j(p) = \chi(p) E_j(p)$ $p \in D$, (6)

which can be considered equivalent source that produces the measured scattered field. This equivalent source is called a contrast source and is measure for the contrasting scatterer in D. The data equation becomes

$f_j = G_S w_j(p)$ $p \in D$, (7)

while the object equation from (2) is rewritten as

$E_j = E_j^{inc} + G_D w_j$ $p \in D$, (8)

Substituting this equation in (6) we obtain an object equation for contrast source rather than for the field

$\chi E_j^{in} = w_j - \chi G_D w_j$ (9)

The data equation (7) is called source type integral equation. Although this equation is linear in the contrast source, it is a classic ill-posed equation. This source type integral equation has served as an essential ingredient in many inversion procedures [11]. The contrast source inversion method [12] recast the inverse problem as an optimization problem in which we seek not only the contrast source but also the contrast itself to minimize a cost functional consisting of two terms, the error norms in data equation and in the object equation.

$$F_n(w_{j,n},\chi_n) = \frac{\sum_j \|\rho_{j,n}\|_S^2}{\sum_j {f_j}_S^2} + \frac{\sum_j \|r_{j,n}\|_D^2}{\sum_j \left\|\chi_{n-1} E_j^{inc}\right\|_D^2} \quad (10)$$

where

$\rho_{j,n} = f_j - G_S w_{j,n}$, $r_{j,n} = \chi_n E_j^{in} - w_{j,n} + \chi_n G_D w_{j,n}$ (11)

The inversion algorithm construct sequences of { $w_{j,n}$ } and {$\chi_n$}which iteratively reduce the value of the cost functional. Although the updating of contrast source and contrast can be carried out simultaneously an alternative updating scheme simplify the algorithm significantly.

***Updating the contrast sources***

Suppose $w_{j,n-1}$ and $\chi_{n-1}$are known, we update $w_j$ in PSO

$w_{j,n} = w_{j,n-1} + v_{j,n}$ (12)

where $v_{j,n}$ is the updated velocity of the particle in nth iteration. Updating process of velocity has been discussed in the next section.

***Updating the contrast***

We note that the contrast is only present in the second term of the cost functional (10) which can be rewritten as

$$F_D(\chi) = \frac{\sum_j \|\chi E_{j,n} - w_{j,n}\|_D^2}{\sum_j \|E_{j,n}\|^2} \quad (13)$$

where $E_{j,n} = E_j^{inc} + G_D w_{j,n}$. In view of the simplicity of the cost functional, it can be minimize analytically by taking the contrast as

$$\chi^{analyt} = \frac{\sum_j w_{j,n} E_{j,n}}{\sum_j |E_{j,n}|^2} \quad (14)$$

## III. SWARM PARTICLE OPTIMIZER

The swarm particle optimization technique is global search technique proposed by Kennedy and Eberhart in 1995.The steps of algorithm are as:

Step 1**:** Initialize swarm (particle) with random position and velocity.

Step 2: Evaluate the fitness of each particle and select the best position *(pbest) and global best (gbest).*

Step 3: Check the convergence of the cost function i.e. F(gbest)< ϵ.

Step 4: If function does not converse, update the velocity and position of the particle.

$w_n = w_{n-1} + v_n$ (15)

where $v_n = av_{n-1}+c_1*r_1(pbest - w_{n-1}) + c_2*r_2(gbest - w_{n-1})$ (16)

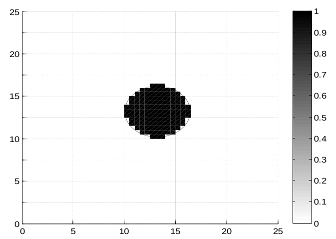
Step 5: Repeat the steps from 2 to 4 until the function converses or maximum number of iteration is reached

In the initialization process N x D swarm has been generated randomly for w(p). Here N is the population of the swarm and D is the number of unknowns (contrast source) in the investigating domain i.e. the dimension the inverse of the problem. The first part of the cost functional contains contrast source, the fitness of the first part is evaluated and minimum value is obtained and considered as pbest of that fitness. The value of contrast source, for which the value of first part of cost functional is minimum, is updated in the equation (14) to obtain contrast analytically. For this value of the contrast fitness of the cost functional is evaluated. Convergence of the cost functional is checked and iteration is either stopped (depending upon the convergence limit set) or velocity and position of the particle is updated.

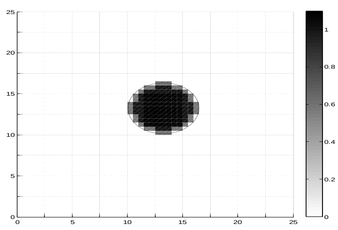
## IV. NUMERICAL RESULTS

### A. *Inversion from synthetic data*

In the experiment a homogeneous circular cylinder has been taken as the scattering object. The assumed parameters are followings:
Considering Fig.1 diameter d= $\lambda_0/4$ ($\lambda_0$ wavelength in free space); frequency f = 3GHz; $\chi$ =1.0; the investigation domain is taken equal to $\lambda_0$; D=625(discretization cell); measurements of field is taken at (j=18 points) at surface S at distance of $3\lambda_0$.The other PSO parameter are (chosen according to suggestions in the literatures) N=30; $c_1=c_2=1.49$,$a_{max}$=0.9 and $a_{min}$=0.4.



(a)

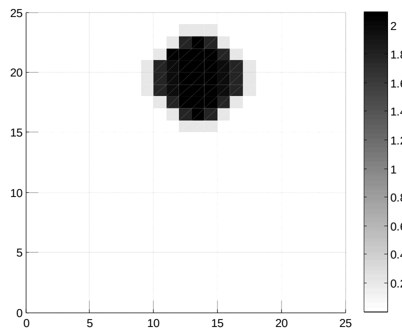


(b)

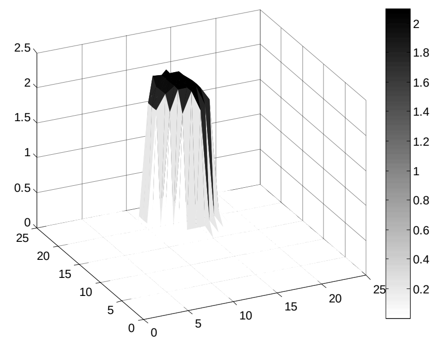
Fig.2 (a) The original profile of the cylinder for reference (b) the profile reconstructed using PSO

#### *Inversion from experimental data*

Institut Fresnel, Marseille, France has measured the electromagnetic data has published it. These data have been used by several researchers for inversion of the scattered field. In the experimental setup the fields are generated and measured by horn antenna. The transmitting horn antenna is moved on a circle around the object at 36 locations at an angle $0^0$ to $360^0$ at step of $10^0$ and fields are recorded around the object at 49 locations at an angle $60^0$ to $300^0$. Due to the physical limitation data has been measured at 49 locations instead of 72 locations. We first consider the scatter field for target of single cylinder experiment file name *dielTM_dec4f.exp*. The relative permittivity of the target is 3±0.3 ($\chi$ = 2±0.3). We consider the data measured at frequency of 4GHz. Secondly we consider the scatter field for target of two cylinder experiment file name *twodielTM_4f.exp*. The relative permittivity of the target in case is also 3±0.3 ($\chi$ = 2±0.3).



(a)



(b)

Fig.3 Reconstruction of off-centered cylinder from Fresenel data *dielTM_dec4f.exp*

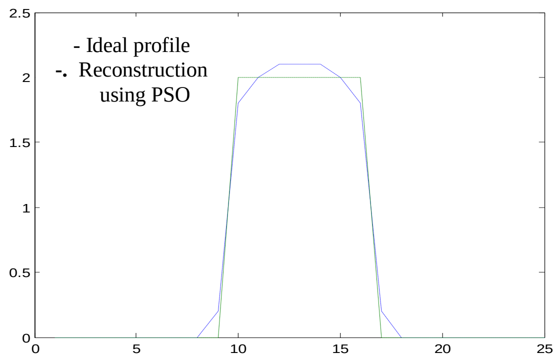



Fig.4 this figure shows the error in reconstruction of off-centered cylinder

For minimization of the cost function (10) we need incident fields in the investigation area D. The transmitting antenna has been approximated line source parallel to the target cylinder. In column 6 and 7 of the Fresnel data set the incident field measured at receiver positions has been given. These incident fields have been measured at receiver positions. But incident fields are required to be calculated in the area of investigation. So, we choose to match our synthetically calculated incident field, due to unit line current source, to the measured incident field [13]. Some other methods can also be used to approximate the transmitting antenna.

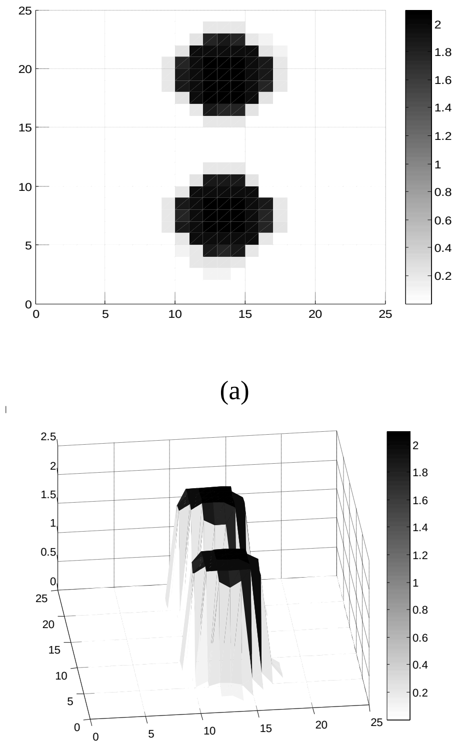



Fig6. Reconstruction of two off-centered cylinders from Fresnel data *twodielTM_4f.exp* d

In Fig.4 the error between the ideal profile of the permittivity of single cylinder and reconstruction of the profile using PSO based on contrast source inversion method has been presented. There is some error but the step change in the permittivity profile is self evident.

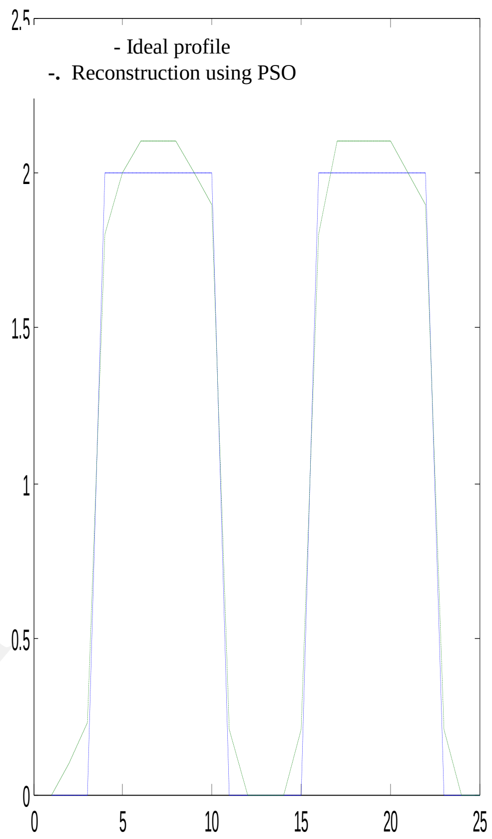



Fig.7 this figure shows the error in the reconstruction two off-centered cylinders

In Fig.7 reconstruction from Fresnel data for two off-centered cylinders has been presented and the position of two cylinders is self evident. For the inversion of the data the inversion area has been subdivided into 25x25 cells.

## V. CONCLUSION

The result shows that the contrast source inversion method with PSO leads to an effective inversion technique. In view of the result obtained and the approximation made for the transmitting and the receiving antennas, the contrast source inversion with PSO is a robust inversion technique. Inversion results can further be improved if a better model of approximation is used for the transmitting and receiving antennas.

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