Effects of Wave Polarization on Microwave Imaging Using Linear Sampling Method

Mehdi Salar Kaleji*
Department of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan, Iran
mehdi.salar@gmail.com
Mohammad Zoofaghari
Department of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan, Iran
zoofaghari@aut.ac.ir
Reza Safian
Department of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan, Iran
rsafian@cc.iut.ac.ir
Zaker Hossein Firouzeh
Department of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan, Iran
zhfiruozeh@cc.iut.ac.ir

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Abstract

Linear Sampling Method (LSM) is a simple and effective method for the shape reconstruction of unknown objects. It is also a fast and robust method to find the location of an object. This method is based on far field operator which relates the far field radiation to its associated line source in the object. There has been an extensive research on different aspects of the method. But from the experimental point of view there has been little research especially on the effect of polarization on the imaging quality of the method. In this paper, we study the effect of polarization on the quality of shape reconstruction of two dimensional targets. Some examples are illustrated to compare the effect of transverse electric (TE) and transverse magnetic (TM) polarizations, on the reconstruction quality of penetrable and non-penetrable objects.

Keywords: Linear Sampling Method (LSM); Inverse Scattering; Polarization; Singular Value Decomposition (SVD).

1. Introduction

Imaging and identification of targets using electromagnetic waves have a long history, e.g., X-ray imaging goes back to the early twentieth century. Waves in microwave frequency range are more interested than those in higher frequencies for imaging and identification. Microwaves have more penetration depth and less destructive impact on targets than higher frequency waves like X-ray so the great tendency exists towards microwave imaging. The purpose of microwave imaging techniques is to retrieve constitutive parameters and shape of scattering objects using the measurement data collected at a distance from scatterers. The unknown objects are illuminated by electromagnetic waves. This problem has many applications in different subjects such as target identification, geophysics, seismic exploration, remote sensing, atmospheric science, ground penetrating radar (GPR) and medical diagnostics such as cancer and hypothermia detection [1].

Imaging approaches based on the solution of an inverse scattering problem are usually grouped into two classes, weak scattering approximation methods and nonlinear optimization methods. The former exploit low or high frequency approximations of the scattering phenomenon to linearize the data-to-unknown relationship and are typically capable of providing only a rough description of the target's morphology when exploited outside of the range of validity of the underlying approximation (Born and Kirchhof inversion approach). Ill-posedness and non-linearity of the inverse scattering problem are the two main complications in the solution process. One way to avoid these problems is the weak scattering approximation which works for certain category of the inverse problems. Different methods are proposed which approximate the scattering based on certain constraints on the scatterer. For example Born approximation is used when the scatterer has small permittivity and is small compared to the wavelength.

Conversely nonlinear optimization methods tackle the inverse scattering problem in its full nonlinearity to determine both the morphology and the electromagnetic contrast of the targets. Optimization approaches seek for the problem's solution by means of a local iterative optimization scheme, as the large number of unknowns makes global optimization generally unreliable, due to the exponential growth of the computational complexity. On the other hand, local minimization is prone to the occurrence of false solutions, so that these methods have to be equipped with regularization schemes, usually based on the available a priori information. Optimization methods are based on minimizing an error function, starting with an initial guess and this guess is optimized during iteration stages. Because in each iteration stage the inverse scattering problem must be solved, such methods

* Corresponding Author

are slower than the others, however accuracy and quality of imaging is great [2]. Examples of two groups of quantitative methods are the modified gradient method [3], distorted Born approximation [4], the contrast source method [5], the subspace optimization method [6] and the least squares optimization method [7].

Another category is qualitative methods which are aimed to find only the shape and location of the target. Linear sampling method is one of the qualitative methods which is reliable, efficient, and has a noticeable high speed of computational operations to find the object shape and location [2]. Colton and Kirsch [8] regularized sampling methods to operate a reconstruction of the region of support of the scatterer from solution norm of a linear integral equation at each pixel point [9]. Proposing a simple and original "physical" interpretation of the linear sampling methods, which shows its relationship with electromagnetic focusing problems have been done in several articles such as [10,11]. A hybrid approach is proposed to inspect three-dimensional homogeneous dielectric scatterers by using microwaves [12] and unlike optimization methods that are based on an initial guess which can lead to an unsuccessful reconstruction results due to approximate priori information, regularized sampling does not require anything to know about the scatterer shape or composition [13]. The LSM is also very fast in comparison with optimization methods as does not involve iteration. In the last years there were quite number of LSM applications in different area such as Trough Wall Imaging (TWI) [14,15], microwave imaging to detect and characterize nonaccessible target concealed into a wall [16,17]. As a newest one, (the LSM) offers a qualitative image reconstruction approach, which is known as a viable alternative for obstacle support identification to the well-studied filtered back projection (FBP), which depends on a linearized forward scattering model [18].

As the operator used in the LSM is linear it does not need born approximation and can be used for a wide range of the scatterers.

In this paper we analyse the effect of various polarizations on reconstruction of PEC and dielectric shapes using LSM. We first calculate the far filed scattered pattern using the method of moment. Then the target is reconstructed with various polarizations such as TM and TE using LSM and compared. The rest of the paper is organized as follows: In Section 2 and 3 the formulation of the LSM and its physical meaning are briefly summarized. In section 4, we investigate noise effect and number of antennas and in section 5, TM and TE polarization results are compared together. Also the paper includes the results of multiple scatterers and coated objects reconstruction taking account the effect of polarization. Buried objects as one the most important applications in the medicine area has been investigated and the polarization influence in two states is compared for the first time. Finally, the conclusion is given in section 6.

2. Formulation of LSM for TM Polarization

2.1 General Two Dimensional Scatterer

At first, we recall the far-field equation and definition of far-filed operator as the basis of LSM. We consider an infinitely long cylinder located in free space which the axis is parallel to z-axis. For the sake of simplicity, we consider the 2-D scalar electromagnetic scattering problem [19]. Denote that Ω is the region of the test. Let assume some transmitter antenna in the far-filed, radiating field approximated by the TM plane waves and the incidence angle Θ_i varing within $(0,2\pi)$. Let us denote $E_z^s(\Theta,\Theta_i)$ the only z-component of the scattered electric filed which is measured by receiving antenna in observation domain $\underline{r} = (r\cos\Theta, r\sin\Theta)$. Let $E_{z,\infty}^s(\Theta,\Theta_i)$ be the far-field pattern defined by the following equation:

$$E_z{}^s(r,\Theta;\Theta_i) = \frac{e^{ik_0 r}}{\sqrt{r}} E_{z,\infty}^s(\Theta,\Theta_i) + O(r^{-1}) \tag{1}$$

where, $k_0 = \omega\sqrt{\mu_0\epsilon_0}$is the wave number of vacuum,ω is operating angular frequency and μ_0 and ϵ_0 are the free - space permeability and permittivity, respectively.

By introducing of operator F^{TM}:$L^2(0,2\pi) \rightarrow L^2(0,2\pi)$ we define far-field equation as below:

$$F^{TM} g = f(\Theta,\underline{r'}) \tag{2}$$

Where

$$F^{TM} g = \int_0^{2\pi} E_{z,\infty}^s(\Theta,\Theta_i) g(\Theta_i) d\Theta_i \tag{3}$$

which g denotes an indicator function relevant to the amplitude of incident field

and

$$f(\Theta,\underline{r'}) = \sqrt{\frac{2}{\pi k_0}} e^{-i\pi/4} e^{-ik_0 r' \cos(\Theta-\Theta')} \tag{4}$$

which coincides with the far-field pattern of the field radiated by an electric current filament located at $\underline{r'} \epsilon\, \Omega$; $\underline{r'} = (r'\cos\Theta', r'\sin\Theta')$. We solve equation (2) for the all points r'. In this case according to LSM, initial current sources with limited power can radiate so that the scattered field of the object due to these ones is equivalent to the radiated filed of a linear line source which is inside of the object. For the numerical realization of the linear sampling method we assume an approximate measured far field pattern $E_{z,\infty}^s$ that is known for different incident plane waves. According to Nystrom approximation equation (3) can be written as [20]:

$$(Fg)(\Theta_j) \cong \frac{4\pi}{n} \sum_{l=1}^{n} E_{z,\infty}^s(\Theta_j,\Theta_l)\, g(\Theta_l). \tag{5}$$

Now we define a matrix:

$$F = \left(\frac{4\pi}{n} E_{z,\infty}^s(\Theta_j,\Theta_l)\right)_{j,l=1}^{n} \tag{6}$$

And two vectors:

$$g = \left(g(\Theta_1), g(\Theta_2), \ldots, g(\Theta_n)\right)^T \tag{7}$$

And

$$f = \left(f(\Theta_1, r'), f(\Theta_2, r'), \dots, g(\Theta_n, r')\right)^T \quad (8)$$

To write matrix form of equation (2) as

$$Fg = f \quad (9)$$

If $\mathcal{G} = \|g\|_{L^2(-\pi,\pi)}$ is the norm of the function g as the solution of the far-filed equation, then $\mathcal{G}$ will be infinite outside the lossless scatterer and finite inside of it. Therefore, the points in the domain where $\|g\|$ is finite are desired to reconstruct the shape of the scatterer. Hence, a regularization scheme must be considered. Using the Tikhonov regularization method [21], $\|g\|$ is given by:

$$\|g\| = \left(\sum_{n=-\infty}^{\infty} \frac{\mu_n^2(f,\psi_n)}{(\alpha+\mu_n^2)^2}\right)^{1/2} \quad (10)$$

where $\{\mu_n, \psi_n, \psi_n^*\}$ is a singular system of operator F^{TM}, (f, ψ_n) are components of f on the singular function ψ_n s, and α is the regularization parameter which is obtained by Morozov's discrepancy principle and should be considered that it usually chooses one hundredth of the largest of singular values [22].

3. Formulation of LSM for TE Polarization

The same approach can be used to consider TE polarization. In this case a new operator F^{TE} like that of equation (3) is identified. F^{TE} is expressed with the same equation as (3) but $E^s_{z,\infty}$ is replaced by $\left({E^s_{x,\infty}}^2 + {E^s_{y,\infty}}^2\right)^{0.5}$ as the magnitude of electric field in TE polarization. Now F^{TM} can be replaced by F^{TE} in equation (2) to formulate LSM for TE polarization.

4. Noise and Antenna Number Effect

In this section we consider the effect of noise and the number of antennas on the quality of reconstruction. Given the analogy between LSM and focusing problems, it follows that an important role in successful reconstruction of shapes is played by the number of primary sources and measurement points. As a matter of fact, if the number of transmitters is low, nothing could be achieved, even in the full aperture case, the desired focused field, while if the number of receivers is low, one could not properly control the synthesized scattered field to match to the desired one. On the other hand, an arbitrary large number of illuminations and measurements, which could overcome these problems, can be largely redundant and may be unnecessarily increases the measurement costs. According to [23] the selection of N antennas where N is given by$N = 2ka\gamma$ is sufficient. The optimal choice for γ depends on the desired accuracy and$\gamma \approx 2$ is a generally convenient one, a is the largest dimension of the scatterer and k is the wave number. The location of object, configuration of the antennas and how they are placed around the object is considered in Fig.1.

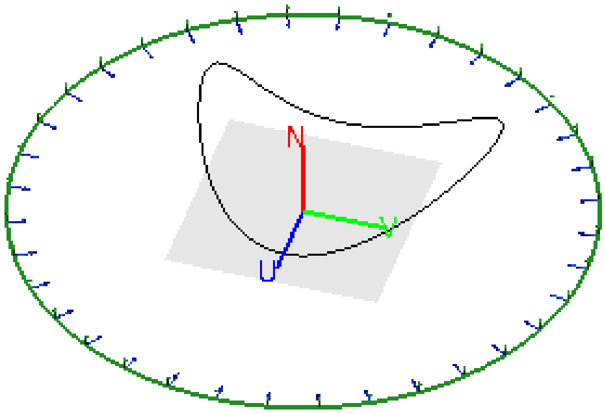

Fig. 1. The Uniform location of antennas around the target

At the end of this section we proceed to the noise issue. We assume that the noise is additive (i.e., $E_s^{\delta}(\theta, \theta_i) = E_s(\theta, \theta_i) + n(\theta, \theta_i)$) and we firstsuppose that, for the sake of simplicity, $n(\theta, \theta_i)$ can be expanded as:

$$n(\theta, \theta_i) = \sum_{-\infty}^{\infty} N_n\, e^{in(\theta-\theta_i)} \quad (11)$$

More details about the effect of noise have been considered in [24]. In the next section we show the effect of noise on reconstruction quality and stability of LSM regarding to noise is considered.

5. Numerical Results and Comparison Discussion

In this section we propose some examples as the numerical results to reconstruct a kite shape object illustrated in Fig.2. We compare the quality of the LSM in TE and TM polarizations for PEC and dielectric targets. The forward scattering data for simulation has been produced by method of moment solver. Also, it is used electric field integral equation (EFIE) for the both of polarizations. Basically, EFIE has been derived by using surface equivalent theorem for PEC objects and volume equivalent theorem (VET) for dielectric ones. That is to say EFIE discretized with pulse basis and delta testing functions. As a test object, a kite plate shape of size about 2.5λ×3λ was used and the parametric equation of this object is written below the figure 2. In all the examples discussed throughout this article, we will use units of free-space wavelength for the scatterer geometry, in this examples the wave number k equals 2π. The cell size of surfaces meshes is 0.01λ and for volume equivalent to a cell density of 520 cells per square dielectric wavelength.

The number of receiving and transmitting antennas is n=38. For the kite-shaped cross section shown in Fig 2. $\|g\|$is given by equation (9) where $\alpha = 0.0001$, and$\frac{1}{\|g\|}$ is plotted for two polarizations in Fig. 2 and Fig. 3 for PEC and in Fig.4 and Fig. 5 for dielectric with$\varepsilon_r = 4$.If α is chosen very small so that it couldn't eliminate small singular values; consequently, the reconstruction boundaries of the shape may be oscillated .On the other hand, the selection of large amount of α leads to an unsuccessful reconstruction. Experimentally selection of $\alpha = 0.0001$ is appropriate. All of the results have been obtained for $k=2\pi$ (the operating frequency is about 300 MHz).

5.1 Polarization Comparison

Comparison between TM and TE polarizations shows that reconstruction of TM is better than TE for PEC objects. On the other hand, TE polarization is more efficient for dielectric objects. It is an expectable result since in forward scattering pattern in dielectric, there are two components of electric field in (i.e. E_x and E_y) TE polarization and just one in TM; thus, the former provides more information for LSM than the latter. However as noted in [8] in resonance frequencies the points where electric field vanishes are better distinguishable in LSM. These points include the boundary of the conducting scatterers in TM polarization and exclude it in TE so the better result is obtained in TM for PEC. It is of great importance to note that both of the results have some problems in the quality of the boundary reconstruction. It refers to the right-hand side of (1). It is proved that the better results are obtained by replacing the right-hand side of (1) by the far field radiated from a dipole instead of monopole [20]. Since the forward pattern has the information of both polarizations, combination of the polarizations leads to a better shape reconstruction which is the future work of the authors.

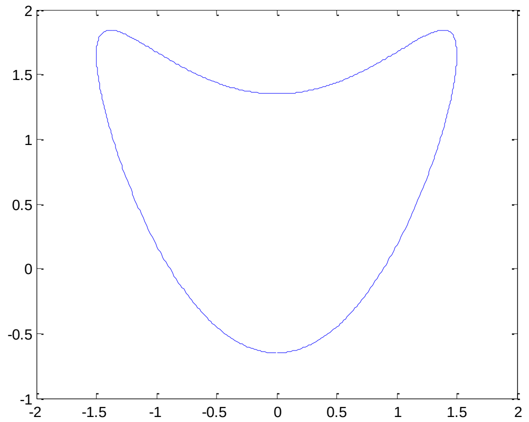

Fig. 2. Kite-Shape scatterer

$$x(t) = (\cos t + 0.65\cos 2t - 0.65, 1.5\sin t), 0 \le t \le 2\pi$$

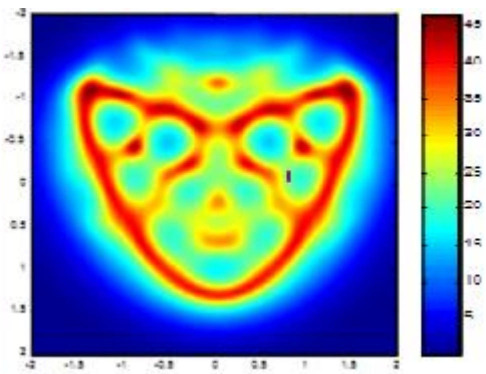

Fig. 3. Reconstruction of PEC object using TM polarization

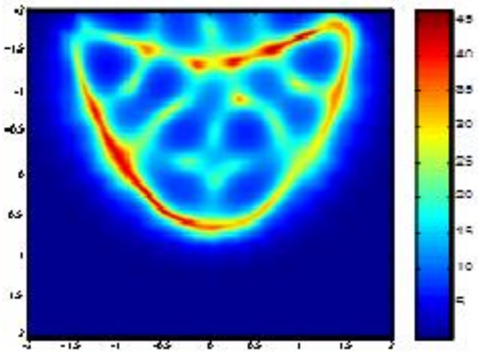

Fig. 4. Reconstruction of PEC object using TE polarization

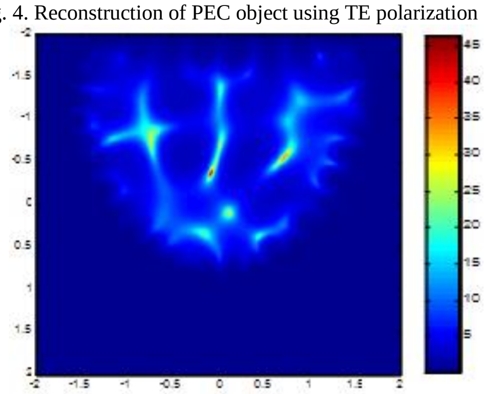

Fig. 5. Reconstruction of dielectric object using TM polarization

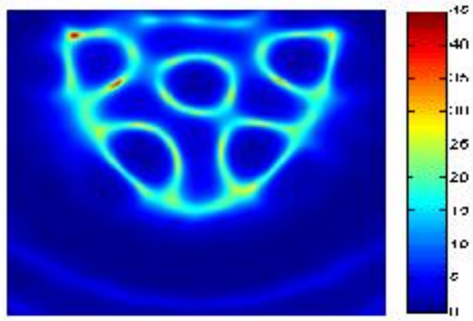

Fig. 6. Reconstruction of dielectric object using TE polarization

5.2 Multi-Scatterers

Here we want to investigate how LSM works for multi scatterers. At first, we study the effect of polarization then pose the number of antenna. Comparison between two polarization TM and TE demonstrated that when we use incident filed with polarization TM, it leads to a better reconstruction toward to TE polarization incident one. It can be observed in Figs. 7 and 8 where we tried for two triangle and circle cross-section shape with 51 transmitter and receiver antennas. On the other hand, if we want to test multi-scatterer with more numbers, we have to increase the number of antennas, as we see in Fig.9, even increasing the number of antennas up to 108 cannot lead to a approvable reconstruction of three shape. However this increase cannot be done arbitrarily. As a result, it can be concluded that we need more transmitting and receiving antennas for LSM to work better as the number of the scatterers increases. It shows the important role of antenna number in the reconstruction of the shape in LSM.

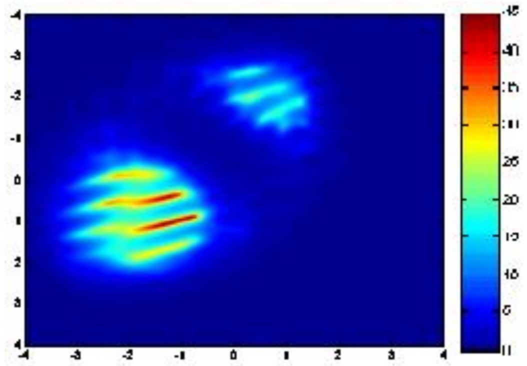

Fig. 7. Reconstruction of multi-scatterers with 51 antennas with Polarization TE

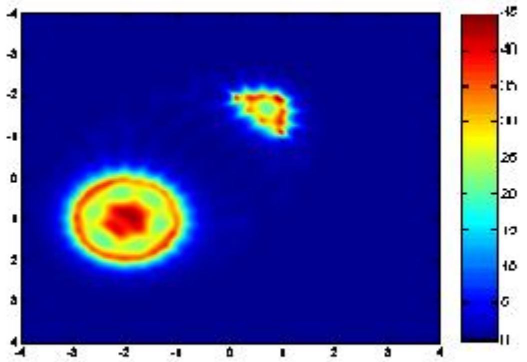

Fig. 8. Reconstruction of multi-scatterer with 51 antennas with Polarization TM

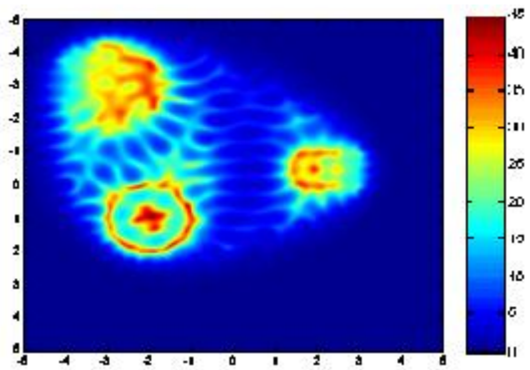

Fig. 9. Reconstruction of three multi-scatterers with 108 antennas with Polarization TM

5.3 Coated Objects

In one part of simulations we considered coated objects. The results for a PEC coated by a dielectric are illustrated in Figs.10 and 11 for two polarizations. We considered a dielectric with thickness of 4 cm.

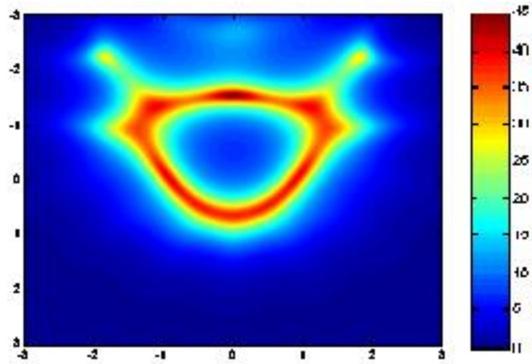

Fig. 10. PEC kite-shape coated with dielectric $\varepsilon_r = 4$ illuminated by TM-polarized waves.

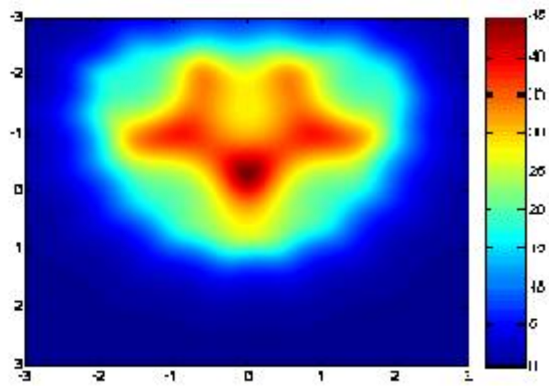

Fig. 11. PEC kite-shape coated with dielectric $\varepsilon_r = 4$ illuminated by TE-polarized waves.

5.4 Buried Objects

One important application of the proposed method is to improve the quality of the shape reconstruction of a hidden object in the other one. It has a numerous applications in medical area such as microwave imaging and detection of cancer cells. Figs 12 and 13 show the location of a PEC object with circular cross section and radius 0.5 lambda, within dielectric object with 2D kite-shape cross section and thickness 4 cm. With comparison between Fifs. 12 and 13, it implies that the TM-polarization result is more clear in the external shape boundary and in contrast the TE one, it has more clarity in the reconstruction of the hidden PEC within the dielectric. To sum up, it seems that, it can be wiser idea to use TE polarization, if the detection of hidden object is more vital.

Despite of this point, the boundary details of internal object in these problems are not so clear and it can be considered as an open problem in LSM to find the shape and material of hidden object more precisely.

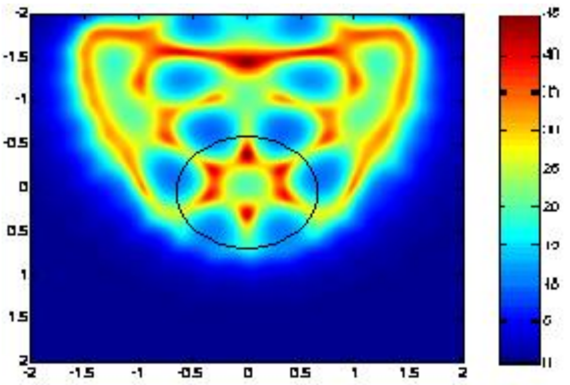

Fig. 12. Dielectric cylinder with $\varepsilon_r = 4$, and thickness 4cm, within a kite- shape cross section, TM polarization.

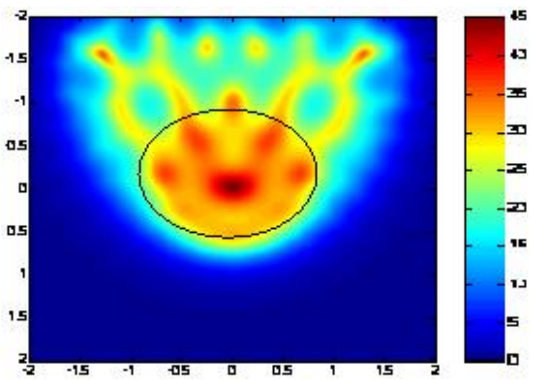

Fig. 13. Dielectric cylinder with $\varepsilon_r = 4$, and thickness 4cm, within a kite-shape cross section, TE polarization.

5.5 Noise Effect

Finally we would like to investigate an important parameter which can affect the reconstruction quality in real areas and that is noise. As a matter of fact, we want to clarify the robustness of LSM against noise for different polarizations. Generally, we know LSM as a method which is not affected by the noise so greatly and here we compare this feature for TE and TM cases. According to Figs. 14 and 16 we can say TM polarization for PEC leads to better results with the same noise condition (SNR=5dB), in contrast in the case of dielectric TE polarization leads to better one on the same condition (Fig. 17 and Fig. 18). This can be implied that it’s more efficient to use TE polarization incident field to reconstruction of dielectric objects in the noisy environments.

Generally linear sampling is the most important method which has stability to the noise effect. Note that we can reduce the effect of noise with increasing the number of antennas, but as we mentioned in section 4 the number of antennas cannot be arbitrary due to high cost of computational complexity and simulation time. Actually there is a limitation for the number of antennas that is defined by noise factor.

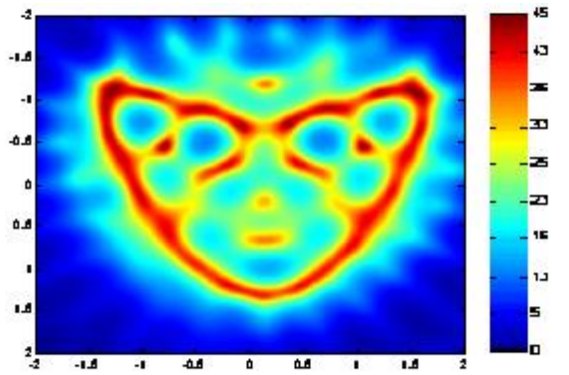

Fig. 14. PEC with noise effect SNR=5dB and TM polarization

The Comparison between Figs. 14 and 15 indicates that as there is more noise at environment, in other words, less SNR; we have a reconstruction with less resolution. The comparison between different polarization and various SNR shows that when we use TM polarization it will be achieved better result toward to TE one in the PEC and on the contrary TE is superior in the case of dielectric scatterer. This issue must be considered that the negative effect of noise on the dielectric is more, related to PEC objects.

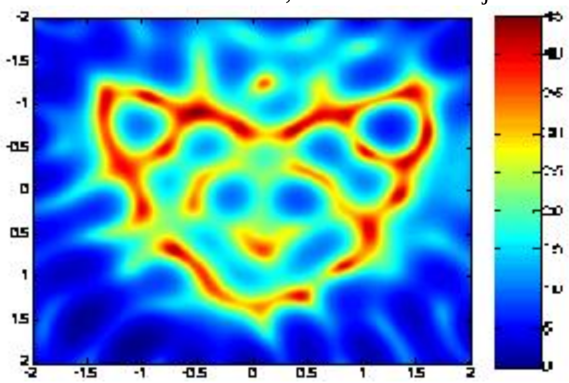

Fig. 15. PEC with noise effect SNR= -5dB and TM polarization

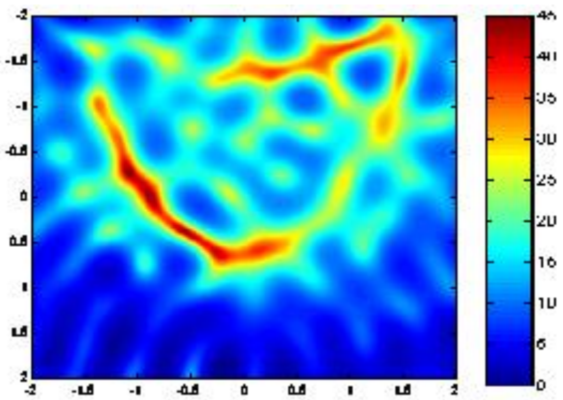

Fig. 16. PEC with noise effect SNR=5dB and TE polarization

For this purpose we tested a dielectric ($\varepsilon_r = 4$) with TM polarization and SNR=-5dB at Fig.15 and shows loss of resolution in the shape reconstruction significantly toward to Fig. 17.

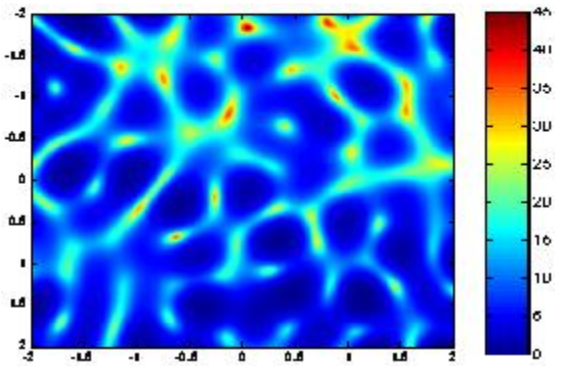

Fig. 17. Dielectric with noise effect SNR=-5dB and TM polarization

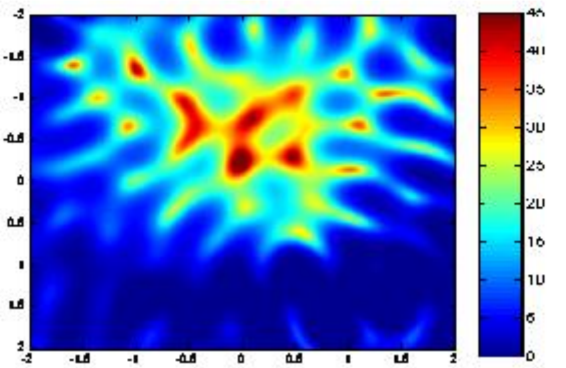

Fig. 18. Dielectric with noise effect SNR= -5dB and TE polarization

6. Conclusions

To put everything in a nutshell, in this paper, we have investigated the performance of linear sampling method (LSM) for TM and TE polarizations based on far-field equation. It was shown by numerical examples that the quality of reconstruction of PEC objects is better than dielectric ones for TM polarization.

However, in the dielectric object, TE polarization operates a little better than TM one. In addition, we have investigated the multiple scattering and coated objects and comparison between various polarizations. Further we posed an open problem about the reconstruction of a hidden shape within other unknown shape that both of them are dielectric especially due to having lots of applications. Moreover we discussed about the stability of LSM toward noise effect and had numerical examples for that.

In the future, we plan to study the combination of TM and TE polarization; because the forward pattern has the information of both polarizations hence it can improve the quality of LSM results. Also we will consider the effect of frequency in various ranges on the shape reconstruction and infer it on the formulation to improve the results.

References

[1] L. Crocco, I. Catapano, L. Di Donato and T. Isernia, "The Linear Sampling Method as a Way to Quantitative," *IEEE Transactions on Antennas and Prpagation*, p. 10, 2012.

[2] D. Colton, H. Haddar and M. Piana, "The linear sampling method in inverse electromagnetic scattering theory," *Inverse Problems 19*, p. S105–S137, 12 November 2003.

[3] L. Souriau, B. Duchene, D. Lesselier and R. Kleunman, "Modified Gradient Approach to Inverse Scattering for Binary Objects In Stratified Media," *Inverse Problems*, vol. 12, pp. 463-481, 1996.

[4] T. Isernia, L. Crocco and M. D'Urso, "New Tools and Series for Forward and Inverse Scattering Problmes in Lossy Media," *IEEE Geosci.Remote Sens.Lett*, vol. 1, pp. 327-331, 2004.

[5] P. VandeBerg and R. Kleiman, "A Contrast Source Inversion Method," *Inverse Problmes*, vol. 13, pp. 1607-1620, 1997.

[6] X. Chen, "Subspace-Based Optimization Method for Solving Inverse Scattering Problmes," *IEEE Trans.Geosci.Remote Sens*, vol. 48, pp. 42-49, 2010.

[7] K. Miller, "Least Squares Methods for Ill-Posed Problems with a Prescribed Bound," *SIAM*, vol. 1, pp. 52-74, 1970.

[8] D. Colton and A. Kirsch, "A simple method for solving inverse scattering problems in the resonance region," *Inverse Problems 12*, p. 383–393, 19 January 1996.

[9] S. N. and K. F. Warnick, "Behavior of The Regularized Sampling Inverse Scattering Method at Integral Resonace Frequencis," *Progress In Electromagnetics Research, PIER 38*, p. 29–45, 2002.

[10] I. Catpano, L. Crocco and T. Isernia, "On Simple Methods for Shape Reconstruction of Unknown Scatterers," *IEEE Trans Antennas Propagation*, vol. 55, p. 1431-1436, 2007.

[11] I. Catapano, L. Crocco, M. D'Urso and T. Isernia, "On the Effect of Support Estimation and of a New Model in 2D Inverse Scattering Problems," *IEEE Trans Antennas Propag*, vol. 55, pp. 1895-1899, 2007.

[12] M. Brignone, G. Bozza, A. Randazzo, M. Piana and M. Pastorino, "A Hybrid Approach to 3d Microwave Imaging by Using Linear Sampling Method and ACO," *IEEE Trans Antennas Propag*, vol. 56, pp. 3224-3232, 2007.

[13] M. Brandfass, A. Lanterman and K. Warnick, "A comparison of the Colton-Kirsch inverse scattering method with linearized tomographic inverse scattering," *Inverse Problems*, vol. 17, p. 1797– 1816, December 2001.

[14] I. Catapano and L. Crocco, "A Qualitative Inverse Scattering Method for Through-The-Wall Imaging," in *IEEE Geoscience and Remote Sensing Lett*, Rome, 2010.

[15] Ö. Özdemir and H. Haddar, "Preprocessing the Reciprocity Gap Sampling Method in Buried-Object Imaging Experiments," *IEEE*, vol. 7, no. Geoscience and Remote Sensing Letters, pp. 756-760, October 2010.

[16] I. Catapano and L. Crocco, "An Imaging Method for Concealed Targets," *IEEE Transaction*, vol. 47, no. Geoscience and Remote Sensing, May 2009.

[17] G. Bozza, M. Brignone, M. Pastorino, M. Piana and A. Randazzo, "A Linear Sampling Approach to Crack Detection in Microwave Imaging," in *In Proceedings of IEEE International Workshop on Imaging Systems and Techniques*, Chni,Crete,Greece, 2008.

[18] H. Alqadah, M. Ferrara, H. Fan and J. Parker, "Single frequency Inverse Obstacle Scattering:A Sparsity Constrained Linear Sampling Method Approach," *IEEE Transaction on Image Processing*, vol. 21, pp. 2062-2075, 2012.

[19] D. Colton and R. Kress, Inverse acoustic and electromagnetic scattering theory, 2nd ed., Berlin: Springer, 1998

[20] I. Catapano, L. Crocco and T. Isernia, "Linear Sampling Mtehod: Physical Interpretation and Guidelines for a Successful Application," in *PIERS proceedings*, Hangzhou,China, 2008.

[21] D. Colton, "Inverse Acoustic and Electromagnetic ScatteringTheory," *Inverse Problems*, vol. 47, 2003.

[22] A. Tikhonov, A. Goncharsky, V. and A. Yagola, Numerical Method for the Solution of Ill-Posed Problmes, Kluwer Academics, 1995.

[23] D. Colton, K. Giebermann and P. Monk, "The linear sampling method for three-dimensional inverse scattering problems," vol. 42, pp. 434-460, 2000.

[24] R. Kress, "Boundary integral equations in time-harmonic acoustic scattering," *Math. Comput. Modelling*, vol. 15, pp. 229-243, 1991.

Mehdi Salarkaleji was born in Babolsar, Iran, in 1986. He received the B.Sc. degree in Electrical Communication Engineering from Shiraz University of Technology (SUT), Shiraz, Iran, in 2008, and the M.Sc. degree in Electrical Communication Engineering (Filed & Wave) from Isfahan University of Technology (IUT), in 2013,Isfahan, Iran. From 2009 to 2011, he was working in HUAWEI company as Microwave Engineer, and from 2013 to 2015 in RCII Lab as a EMC/SAR specialist. Now he is a PhD student In Electrical Engineering at Wayne State University (WSU), Detroit, MI, USA. His research interests include Inverse & Forward Scattering Problems, Microwave Imaging, Computational Electromagnetic and Antenna.

Mohammad Zoofaghari received the B.Sc. and M.Sc. degrees in Electrical Engineering from the Isfahan University of Technology, Isfahan, in 2008 and 2010, respectively, and he is currently working toward the Ph.D. degree in Amirkabir University of Technology, Tehran. His research interests include Scattering of Buried Objects in Multi-layers Media with Rough Interfaces, Through and Intra Wall Imaging and Inverse Scattering.

Reza Safian received the B.Sc. degree in Electrical Engineering from the Isfahan University of Technology, Isfahan, Iran, in 1999, the M.Sc. degree in Electrical Engineering from McMaster University, Hamilton, ON, Canada, in 2003, and the Ph.D. degree in electrical engineering from the University of Toronto, Toronto, ON, Canada, in 2008. From 1999 to 2002, he was an RF Design Engineer with the Electrical and Computer Engineering Research Center (ECERC), Isfahan University of Technology. In 2008, he joined the faculty of the Isfahan University of Technology, where he is currently an Assistant Professor with the Electrical and Computer Engineering Department. His technical interests include Basic Electromagnetic Theory, Microwave Circuits, THz and Microwave Imaging.

Zaker Hossein Firouzeh was born in Isfahan, Iran, in 1977. He received the B.Sc. degree in Electrical Engineering from Isfahan University of Technology (IUT), Isfahan, in 1999 and the M.Sc. and Ph.D. degrees in Electrical Engineering from Amirkabir University of Technology (AUT), Tehran, Iran, in 2002, and 2011, respectively. He was a Research Engineer at Information Communication Technology Institute (ICTI) of IUT from 2002 to 2006. He experienced in design and implementation of antenna, Radar, and wireless communication systems. He currently works as an assistant professor in Department of Electrical and Computer Engineering, Isfahan University of Technology. He is the author or coauthor of more than 40 papers in journals and conference proceedings. His current research interests include antenna design and measurements, numerical techniques in electromagnetic, wave propagation and scattering, and EMC/EMI.