Microwave Imaging

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Abstract -*Microwave Imaging is an imaging technique which is a non-invasive method and it uses non ionizing electromagnetic (EM) signals in the frequency range of hundreds of megahertz to a few gigahertz. It is an emerging technology which can replace the present imaging techniques like X-ray, Computerised tomography (CT scanning) ,Magnetic Resonance Imaging(MRI) .Microwave Imaging is more advantageous than the present techniques where X-ray and CT scanning uses the ionizing radiations which can cause damage to the healthy tissues and MRI which consumes more power and huge equipment setup. The microwave imaging equipment consists of a microwave source, a receiver, an antenna-array for transmitting the signals, and a radiofrequency switch to switch between different antenna elements in the antenna-array. This Microwave Imaging equipment costs a fraction of the cost of the equipment for other Imaging techniques, making microwave imaging a cost-effective technique.*

Key Words: Non ionizing Electromagnetic signals, Radio Frequency switch, Antenna array

1. INTRODUCTION

Microwave imaging is mainly used in medical imaging which is used to visualize the interior of the body of both healthy and diseased subjects through a non-invasive method. Generally imaging of the body is done for clinical analysis and detection of any abnormality. The most common examples of medical imaging are imaging done in different phases of cancer management, imaging for detecting bone fracture, and identifying tumors. Depending upon the application, clinical data for imaging can be obtained through a variety of techniques like x-rays, magnetic resonance imaging(MRI), computed tomography(CT), ultrasound(US), and positron emission tomography. These techniques provide images with different resolutions. Some of the techniques like MRI are costly due to the high maintenance and implementation cost of the equipment where a 50,000 times of the magnetic field is generated. So most of the equipment is large in size and is not portable which cannot be used for regular monitoring purposes. Some of the techniques use ionizing radiations that may damage the healthy tissues. For example, MRI can provide images with high resolution which can be used for various applications such as brain imaging for tumor detection. But the problem with this MRI is the equipment which is costly and has high maintenance costs. Similarly, CT produces images with a good spatial resolution, but uses x-rays which are highly ionized and capable of ionizing and effecting the molecular bonding of healthy tissues, posing a possible health risk. So CT cannot be used reliably for imaging. Positron emission tomography is said to provide more information when it comes to tissue imaging or providing functional information, but it suffers from poor spatial resolution. Microwave Imaging is an imaging technique using non ionizing electromagnetic (EM) signals in the frequency range of hundreds of megahertz to a few gigahertz. It is emerging as an alternative imaging technique to the aforementioned medical imaging techniques due to several advantages. As it uses non-ionizing, low power EM signals, it is a low health-risk method. Moreover, the microwave imaging equipment consists of a microwave source, a receiver, an antenna-array for transmitting the signals, and a radiofrequency switch to switch between different antenna elements in the antenna-array. Microwave imaging equipment which costs very less a fraction of the cost of the equipment for other diagnostic methods, making microwave imaging a cost effective technique. Moreover, the equipment is portable and can fit inside an ambulance for fast diagnosis of life-threatening conditions, like stroke while a patient is still on the way to the hospital. However, there are some disadvantages and challenges for medical microwave imaging. The biggest disadvantage is that the images obtained from microwave imaging are low spatial resolution images. Over the years, medical microwave imaging has advanced significantly with the development of robust imaging algorithms and simple, but fast data acquisition hardware supported by the advancements made in microelectronics, material science, and embedded systems. To this end, proof-of-concept of medical microwave imaging for various applications has been reported in the literature. Imaging for various pathological conditions that have been investigated are brain imaging for strokes, cerebral edema, breast cancer, bone imaging, heart imaging , and joint tissues. The physical basis of medical microwave imaging is the tissue-dependent dielectric contrast that is used to reconstruct signals and images using radar-based or tomographic imaging algorithms. Different tissues have different dielectric properties that are characterized by relative permittivity and conductivity. Moreover, tissue of the same kind, if tumorous, will have different dielectric properties. Due to this difference, the interaction of the EM signals will be different for different tissues. It can be exploited by different reconstruction algorithms to construct a map or an image, either in D or D, that shows different tissue dielectric properties or the location of a tumor inside the body. Further, the reconstruction algorithms can be categorized into quantitative and qualitative imaging algorithms. A map or the image of the distribution of the various tissues with the values of dielectric properties in the body can be generated by quantitative imaging algorithms. Quantitative algorithms are usually based on the inverse EM scattering problem. On the other hand, qualitative imaging algorithms use radar-like techniques for image generation to differentiate the tumorous tissues from the normal tissues. Tumorous or the malignant tissues usually scatter EM signals stronger than other normal tissues and can be detected by qualitative imaging algorithms.

2. LITERATURE SURVEY

2.1 Research paper on: **"A Tomograph Prototype for Quantitative Microwave Imaging: Preliminary Experimental Results"**

A new prototype of an atom graphic system for microwave imaging is presented in this paper. The target being tested is surrounded by anand-hoc3D-printed structure, which supports sixteen custom antenna elements. The transmission measurements between each pair of antennas are acquired through a vector network analyzer connected to a modular switching matrix. The collected data are inverted by a hybrid nonlinear procedure combining qualitative and quantitative reconstruction algorithms. Preliminary experimental results, showing the capabilities of the developed system, are reported.

2.2 Research paper on: **"Developments in Electrical-Property Tomography Based on the Contrast-Source Inversion Method"**

The main objective of electrical-property tomography (EPT) is to retrieve dielectric tissue parameters from ˆ B+ 1 data as measured by a magnetic-resonance (MR) scanner. This is a so-called hybrid inverse problem in which data are defined inside the reconstruction domain of interest. In this paper, we discuss recent and new developments in EPT based on the contrast-source inversion (CSI) method. After a short review of the basics of this method, two-and three-dimensional implementations of CSI–EPT are presented along with a very efficient variant of 2D CSI–EPT called first-order induced current EPT (foIC-EPT). Practical implementation issues that arise when applying the method to measured data are addressed as well, and the limitations of a two-dimensional approach are extensively discussed. Tissue-parameter reconstructions of an anatomically correct male head model illustrate the performance of two- and three-dimensional CSI–EPT. We show that 2D implementation only produces reliable reconstructions under very special circumstances, while accurate reconstructions can be obtained with 3D CSI–EPT.

2.3 Research paper on: **"Contraction Integral Equation for Three-Dimensional Electromagnetic Inverse Scattering Problems"**

With the help of the FFT type twofold subspace-based optimization method (TSOM), when handling the highly nonlinear problems with strong scatters, those with higher contrast and/or larger dimensions (in terms of wavelengths), the performance of the inversions with CIE-I is much better than the ones with the LSIE, wherein inversions usually converge to local minima that may be far away from the solution. In addition, when handling the moderate scatters (those the LSIE modeling can still handle), the convergence speed of the proposed method with CIE-I is much faster than the one with the LSIE. Secondly, we propose to relax the contraction mapping condition, i.e., different contraction mappings are used in updating contrast sources and contrast, and we find that the convergence can be further accelerated. Several numerical tests illustrate the aforementioned interests.

2.4 Research paper on: **"Qualitative Methods for the Inverse Obstacle Problem: A Comparison of Experimental Data"**

Qualitative methods are widely used for the solution of inverse obstacle problems. They allow one to retrieve the morphological properties of the unknown targets from the scattered field by avoiding dealing with the problem in its full non-linearity and considering a simplified mathematical model with a lower computational burden. Very many qualitative approaches have been proposed in the literature. In this paper, a comparison is performed in terms of performance amongst three different qualitative methods, i.e., the linear sampling method, the orthogonality sampling method, and a recently introduced method based on joint sparsity and equivalence principles. In particular, the analysis is focused on the inversion of experimental data and considers a wide range of (distinct) working frequencies and different kinds of scattering experiments.

3. EXISTING METHODOLOGY

3.1 X-rays

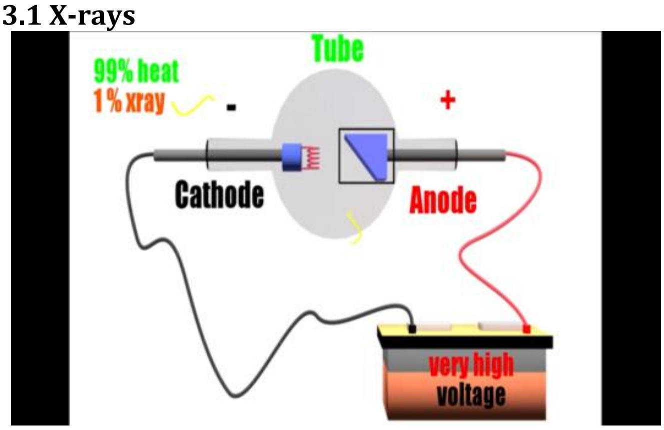

Fig -1:X-rays

Uses 5k to 400kv of DC voltage. The electrons coming from the cathode with a high enough velocity struck the anode then X-rays are produced. When these X-rays are passed through the body. Bones contain much calcium, which due to its relatively high atomic number, x-rays are absorbed. This reduces the amount of X-rays reaching the detector .so the shadow of the bones are formed which will be visible on the radiograph .X-ray production processes are inefficient, with only about one percent of the electrical energy used by the tube converted into X-rays, and thus most of the electric power consumed by the tube is released as waste heat and they emit ionizing radiation .X-ray photons carry enough energy to ionize atoms and disrupt molecular bonds and therefore harmful to living tissue. The ionizing capability of X-rays can be utilized in cancer treatment to kill malignant cells using radiation therapy.

3.2 COMPUTERIZED TOMOGRAPHY (CT SCANNING)

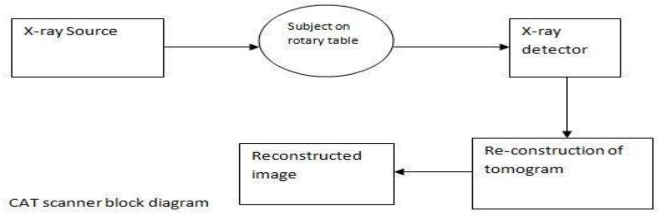

Fig -1 : Computerized Tomography

X-ray source : X-ray beam passes through the body around 360 degrees in a rotating table

Rotary table: The subject is placed in a rotary table. During the process, the tissues absorb small amounts of radiation depending on the intensity of the X-ray beam.

X-ray detector: The X-ray detectors are placed in a ring shaped apparatus which rotate around the patient. They detect the X-ray beam intensity of each tissue and feed it to a computer. Actually the rays coming out of the detector are converted into electronic signals due to the light sensitive nature of the detectors.

Reconstruction of tomogram: CT produces a group of data which can be manipulated and processed to demonstrate various bodily structures based on their ability to block the X-ray beam. It is called 'windowing' technique. The reconstruction of tomograms is done by using a suitable computational algorithm using a computer. By using a computer the image can be produced in a television screen. This is called tomogram and it can provide a very accurate cross sectional view of any area of the body. To reconstruct the image, a number of mathematical operations have to be done and for this we use different computational tools. This produces more ionized radiation due to more X-ray radiation which is more health hazard.

3.3 MAGNETIC RESONANCE IMAGING

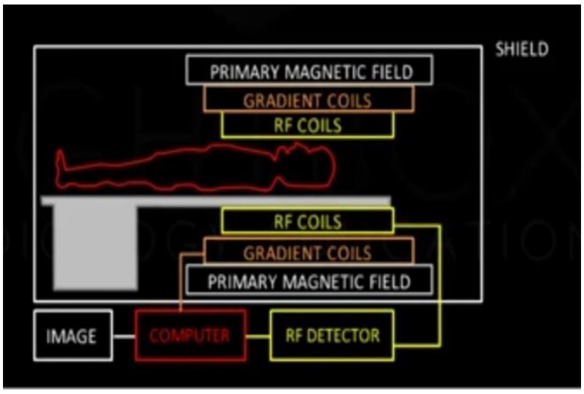

Fig -3: Magnetic Resonance Imaging

It Uses magnetic fields and radio wave frequency. As our body consists of 70% of water H2O which consists of hydrogen atoms. In hydrogen atoms, protons have magnetic properties. These protons of the hydrogen atom present in the body are used in the process of imaging. In the absence of the field protons are randomly oriented. By applying the magnetic field protons are aligned parallel to the applied magnetic field, few having extra energy are aligned antiparallel. But the resultant will be parallel to the magnetic field direction. Protons are not static, they rotate about its axis with some freq which is given by the Larmor precession frequency equation $f= \gamma * B$

γ is the gyromagnetic ratio(depends on charge and mass)

Below given are the larmor frequencies for the corresponding magnetic field applied.

1 tesla = 42.58MHz

2 tesla =85.16MHz

3 tesla =127.74MHz

When RF pulses with more than larmor precession frequency are applied, direction of protons are changed. When RF pulses are stopped, again protons will be aligned in magnetic field direction. In this way 1000 times has done Protons due to the magnetic field and RF pulses they change their alignment, at this point signals are received by using software algorithms, image is constructed. Here the power required for the production of magnetic fields is high and the equipment is large where we cannot use it for monitoring purposes and costlier.

4. PROPOSED METHODOLOGY

4.1 Dielectric Properties of Tissues

The fundamental notion of microwave imaging is the tissue dependent dielectric contrast that is used to reconstruct images using radar-based or tomographic imaging techniques. So before going to the details of the microwave imaging setup and algorithms it is better to know how dielectric properties of tissues help in Imaging.

Different types of tissues, including both normal and malignant tissues of the same kind, have distinct electrical properties. The dielectric properties of the tissue consist of the relative permittivity and the conductivity. The difference occurs primarily due to the difference in the water content in the tissue.

For example, fat is a low water content tissue having low relative permittivity and conductivity. On the other hand, muscle is a high water content tissue having high relative permittivity and conductivity at microwave frequencies. Further, a tumorous or a malignant tissue has a higher rate of metabolism, resulting in more blood flowing through it. This changes the electrical properties of the tissue from its normal healthy kind. Apart from the difference in the water content in healthy and malignant tissues, a variety of other factors have been found that explain the difference in electrical properties between healthy tissues and malignant tissues. These include necrosis and inflammation causing breakdown of the cell membrane, charging of the cell membrane, change in the dielectric relaxation time, and difference in the sodium content. This difference in the electrical properties of the tissues results in the variation in the scattered field by the different tissues. This forms the basis of the microwave imaging.

Percentage change in the dielectric properties of malignant tissues with respect to the healthy tissue from 50 to 900MHz are shown in the Fig-4

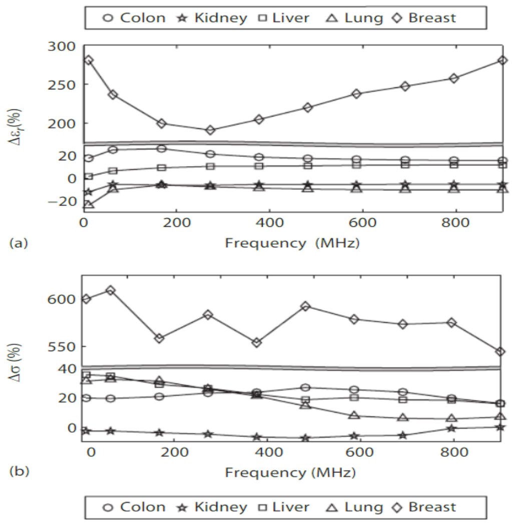

Fig-4: (a)percentage change in the relative permittivity (b)percentage change in the conductivity

But there are some problems with the dielectric properties of the tissues. For example, for some tissues, the difference between the normal and malignant tissue may be low. This may result in a very small difference in the scattered field from the normal and malignant tissues. For example, there exists a large contrast between cancerous breasts and healthy fatty tissues. This difference is small when the cancerous tissue is compared with the healthy glandular or the fibro-connective breast tissue. Hence, the detection of cancerous tissue in a close vicinity of the glandular tissue may be a challenging task with microwave imaging. Moreover, the presence of multiple tissues with different properties results in a complex scattering environment. To solve these challenges, either use of a high dynamic range system is required to capture the small difference in the scattered field or the use of contrast agents is proposed to enhance the electrical properties of the malignant tissues.

4.2 Microwave Imaging Setup

It consists of several antennas located around the body to be imaged. One antenna transmits at a time: it is connected to the transmitter and the scattered signal from the body is collected by the rest of the antennas that are connected to the receiver. Usually, there is an RF switch that quickly switches between different antennas, such that all or some antennas act as a transmitter while the rest of the antennas are connected to the receiver. Between the antennas and the body, there is a homogeneous matching medium. The matching medium helps in reducing the reflections by coupling the signal to the body. This is because of the fact that, in the absence of the matching medium, a high reflection may occur between the tissue and the medium, which is the air in which the antenna system is kept. This would result in a weak signal that could penetrate the body. Hence, matching medium helps in reducing this reflection, and a relatively higher strength of the signal can penetrate the body. A simple matching medium that has been used is water. The scattered signal is collected by the antenna and processed by the receiver to get meaningful signal data, the data is transferred to a computer. The computer executes the imaging algorithm to generate the image of the body. By the analysis of the generated image, the position of the tumor can be detected.

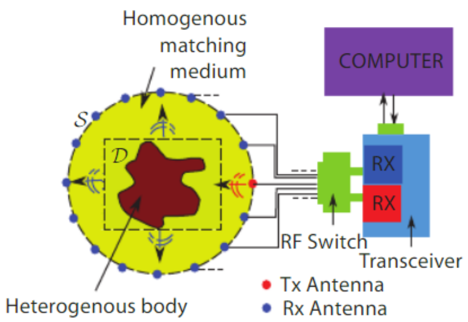

Fig 5: Basic setup of Microwave Imaging

The basic setup for microwave imaging in a two-dimensional case when one antenna (TX) transmits the signal and all other antennas (RX) are in receiving mode.

D-bounded Domain

S-measurement Domain

The imaging domain contains the heterogeneous body to be imaged. E measurement domain contain the transmit and receive antennas. The whole system is in a homogeneous medium that acts as a matching medium. The RF switch switches between different antennas, such that all or some antennas act as a transmitter while the rest of the antennas are connected to the receiver. The transceiver is connected to a computer to which the collected signal data is transferred. The computer also executes the imaging algorithm.

4.3 Microwave Imaging Algorithms

Microwave Imaging algorithms can be divided into two categories, namely, quantitative and qualitative. Quantitative imaging algorithms generate the image with the distribution of the electrical properties of the body. On the other hand, qualitative imaging algorithms generate the image of the intensity of the scattered signal that shows the location of the strong scatterer as the tumor.

4.4 Quantitative Imaging Algorithms

Quantitative imaging is also called tomography. The microwave tomography problem is formulated in terms of electric fields. To formulate the problem, two domains are defined : bounded domain (D) and the measurement domain (). The bounded domain is a domain in which the body to be imaged is enclosed. The antennas are located on the measurement domain. Three electric fields are defined for the purpose: the incident field Einc on D, the total field Etotal in D, and the scattered field Escatt on S.

4.5 Qualitative Imaging Algorithms

Qualitative imaging algorithms are similar to radar-based algorithms where the objective is to detect strong scattering objects. In case of medical microwave imaging, the malignant or the tumorous tissue is a strong scatterer due to higher dielectric properties than the surrounding tissues. Various radar-based imaging algorithms to focus the tumor, such as confocal microwave imaging, beam forming, and tissue sensing adaptive radar are used. Ultra-wideband (UWB) signal is used for qualitative imaging to have a good time resolution. In qualitative imaging, each antenna transmits a short pulse at a time (UWB in frequency domain),and the backscatter response is received by the same antenna. The backscatter response consists of the tumor response, scatter from the skin, and backscatter from other tissues. Signal processing is used to reduce the effect of the skin and the backscatter from other tissue, to enhance the signal backscattered by the tumor. For example, in confocal microwave imaging, the processed backscattered waveform at each of the antennas is integrated over time to obtain Bt integrated waveforms, where t is the number of the transmit antennas. The reconstructed image is then created by time-shifting and summing data.

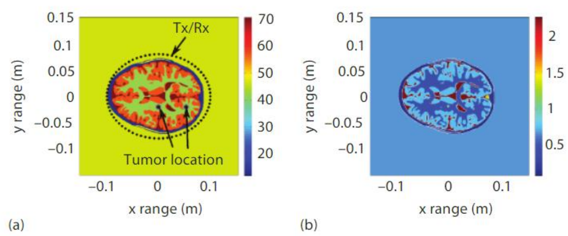

Fig 6: Example for brain tumor detection

5. COMPARISON OF PROPOSED METHODOLOGY WITH EXISTING METHODOLOGY

The existing methodologies are X-ray, Computerised tomography (CT scanning) and Magnetic Resonance Imaging. In X-ray and CT scanning the radiations are highly ionized which affects the molecular bonding of healthy tissues and may cause cancer and the voltage used to generate X-rays is very high DC voltage where only one percent of electrical energy is converted into X-rays and remaining electrical energy is wasted as heat energy. So the X-ray scanning is not effective and causes damage to the healthy tissues. Magnetic resonance

Imaging does not emit radiations but the power used to generate magnetic fields is too high.

Microwave Imaging produces non-ionized radiations with low equipment cost and the power requirement is also low which makes it more effective than other medical imaging techniques.

Imaging Techniques	Frequency Range	Radiation Safety	Image Resolution	Cost
X-Ray	3*10^16 to 3*10^19 Hz	High	Low	Low
CT scanning	3*10^16 to 3*10^19 Hz	Very High	Moderate	High
MRI	10 to 300M Hz	Low	Moderate	High
Microwave Imaging	300 MHz to 300 GHz	Low	High	Low

Table 1: Comparison table for different medical Imaging techniques

6. MERITS

1. Includes low cost
2. use of safer non-ionizing radiation
3. The ability to image bulk-electrical tissue properties.
4. The ability to provide functional imaging without the use of contrast agents.

7. DEMERITS

The images obtained from Microwave Imaging are low spatial resolution images.

8. APPLICATIONS

1. Nondestructive testing and evaluation
2. medical imaging(brain stroke monitoring and cancer detection)
3. concealed weapon detection at security checkpoints
4. structural health monitoring, and
5. Through-the-wall imaging.

9. CONCLUSION AND FUTURE DIRECTIONS

This shows an alternative imaging technique called microwave imaging for medical applications that uses non ionizing electromagnetic (EM) waves for imaging unlike ionizing x-rays. Moreover, microwave imaging equipment is low-cost and can be easily maintained, unlike costly and high-maintenance equipment of other imaging modalities like MRI. Various research reports have shown the feasibility of using microwave imaging for applications such as brain stroke and tumor detection, breast cancer detection, heart imaging, and bone imaging.

10. REFERENCES

[1] Meaney, P.M.; Goodwin, D.; Golnabi, A.H.; Zhou, T.; Pallone, M.; Geimer, S.D.; Burke, G.; Paulsen, K.D. Clinical Microwave Tomographic Imaging of the Calcaneus: A First-in-Human Case Study of Two Subjects. IEEE Trans. Biomed. Eng. 2012, 59, 3304–3313. [CrossRef] [PubMed] 2. Ghasr, M.T.; Horst, M.J.; Dvorsky, M.R.; Zoughi, R. Wideband microwave camera for real-time 3-D imaging. IEEE Trans. Antennas Propag. 2017, 65, 258–268.

[2] Oliveri, G.; Randazzo, A.; Pastorino, M.; Massa, A. Electromagnetic imaging within the contrast-source formulation by means of the multiscaling inexact Newton method. J. Opt. Soc. Am. A 2012, 29, 945–958.

[3] Sheen, D.M.; McMakin, D.L.; Hall, T.E. Three-dimensional millimeter-wave imaging for concealed weapon detection. IEEE Trans. Microwave Theory Technol. 2001, 49, 1581–1592.

[4] Di Donato, L.; Crocco, L. Model-based quantitative cross-borehole GPR imaging via virtual experiments. IEEE Trans. Geosci. Remote Sens. 2015, 53, 4178–4185.

[5] De Zaeytijd, J.; Franchois, A.; Geffrin, J.M. A new value picking regularization strategy-Application to the 3-D electromagnetic inverse scattering problem. IEEE Trans. Antenna Propag. 2009, 57, 1133–1149.

[6] Chaumet,P.;Belkebir,K.Threedimensionalreconstructionfromrealdatausingaconjugategradient-coupled dipole method. Inverse Probl. 2009, 25, 024003.

[7] Donoho, D.L. Compressed sensing. IEEE Trans. Inf. Theory **2006**, 52, 1289–1306. Baraniuk, R.G. Compressive sensing [lecture notes]. IEEE Signal Process. Mag. **2007**, 24, 118–121.

[8] Pierri, R.; Persico, R.; Bernini, R. Information content of the Born field scattered by an embedded slab:multifrequency, multiview, and multifrequency—Multiview cases. JOSA A **1999**, 16, 2392–2399.

[9] Crocco, L.; Di Donato, L.; Catapano, I.; Isernia, T. An Improved Simple Method for Imaging the Shape of Complex Targets. IEEE Trans. Antennas Propag. **2013**, 61, 843–851.

[10] Agarwal, K.; Chen, X.; Zhong, Y. A multipole-expansion based linear sampling method for solving inverse scattering problems. Opt. Express **2010**, 18, 6366–6381.