Microwave Imaging Using the Kirchhoff Migration Algorithm with Monostatic Configuration

Kesia C. Santos, Carlos A. Fernandes and Jorge R. Costa

***Abstract*— In this work is studied the microwave imaging using an (Ultra-Wideband) UWB antenna, for detection of lesions in tissues as an alternative for the use of X-ray. This paper describes the necessary procedure to realize the target (tumor) detection using microwave imaging. Despite the difference in the materials of the target and the surrounding medium, the procedure is the same as that used for phantoms that mimics the tissue and tumor. To simplify the understanding of the procedure, the target is a metallic sphere and the environment is the air. The Kirchhoff migration algorithm was implemented for the image reconstruction.**

Keywords*— *Microwave Imaging, Kirchhoff Migrationt; UWB microstrip antenna

I. INTRODUCTION

Breast cancer is the second most frequent in the world and also the most common among women. About 25% new cases per year are estimated by the National Cancer Institute (INCA) of Brazil. In 2016 57,960 new cases of breast cancer are estimated in Brazil [1].

Despite considered, by mastologists, a good prognosis cancer, if early detected and treated, breast cancer mortality rates remain high in Brazil (14 deaths per 100,000 women in 2013) [1]. In Brazil, the Health Ministry recommends mammography every two years for women in the age between 50 to 69 years [2].

The strategy for premature detection of breast cancer is the screening and diagnosis to identify lesions suggestive of cancer and, with this initial result, refer women with abnormal results for diagnostic and treatment [3].

The mammography is the technique most used in the detection of breast cancer. The technique analyzes the images based on breast abnormalities (densities and structure inhomogeneities). It is capable of detecting micro-calcifications (considered an early sign of breast cancer) [4].

However, in younger patients, which have dense breasts, this technique may be inefficient. Besides that, this technique has health risk, when often made, as it involves X-ray radiation. In mammography there is the uncomfortable compression of the breast to improve the image visualization [5], [6].

Another technique used is the magnetic resonance imaging (MRI), but this technique involves the use of a contrast agent (which may be dangerous to some patients). Furthermore, it is an expensive technique. It is most applied in patients with breast implant [6].

The ultrasound is the technique most indicated for younger patients, when yet there is no indication for mammography. This method can distinguish between liquid cyst and solid tumor, which are detected by mammography (technique applied together with mammography). But, the ultrasound presents low capacity in the detection small lesions [4].

The use of microwave systems for target detection is an area of research that is increasing in last years [8]-[12]. In medical imaging, research using microwave breast cancer detection has shown very promising. In this technique, there is no breast compression and health risk by X-ray radiation. It can be used in pregnant women and of any age (younger and old).

The difference between normal tissue and malignant tissues in microwave frequencies is well defined. There is a relationship between the complex permittivity of these biological tissues and their scattered fields. So, normal breast tissue (which has low permittivity) is transparent to microwaves. However, when a lesion is present in the tissue (the permittivity is greater) there is an increase in the scattered field. This scattered field can be recorded and analyzed [6], [7].

The microwave imaging technique has the capacity to detect small lesions [6]. It is a less expensive technique, compared to mammography and ultrasound equipment. The imaging process is fast and more specific (to detect only lesions in breast). Thus, it may be available in all health centers. It can be a low cost and fast alternative for a first screening test of the breast tumors detection. The use of this technique does not replace the necessity of the mammography, but to reduce its frequency [13].

Besides, the imaging by X-ray presents an environmental cost. The use of radioactive substances involved in the process demands specific health-care waste disposal procedures. According to the World Health Organization (WHO) the radioactive waste should be placed in large containers with thick concrete walls (minimum 25 cm) or drums [14]. Since this rule is a recommendation of the World Health Organization, each country may or may not follow it. In some disaster situations, such as war, these rules may be despised, increasing the possibility of an environmental contamination. Countries in developing economies may not follow some recommendations, resulting in areas with radioactive risk.

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In this work microwave imaging is studied using an UWB (Ultra-Wideband) antenna, developed before by the research group, for detection of abnormalities as an alternative for the use of X-ray. This paper describes the necessary procedure to perform hidden target detection. Despite the difference in the materials of the target and surrounding medium, the procedure is the same. To simplify the understanding of the procedure, the hidden object is a metallic sphere and the medium is air. The Kirchhoff migration algorithm was implemented for the image reconstruction.

This paper is organized as follows. The section II presents the antenna used in this work for target detection. The description of the Kirchhoff migration algorithm implementation is given in section III. In the section IV is presented the monostatic simulation process for the target identification. Simulations results are presented in the section V. Finally, section VI summarizes the results and concludes this work.

II. XETS ANTENNA

For the purpose of this work, it is used a wideband antenna already available in our research group, only adapting the antenna to the desired frequency, the Exponentially Tapered Slot – XETS [15]. The operation bandwidth of the antenna is 3.1 to 10.6 GHz. The geometry and dimensions of the XETS are presented in the Fig. 1 and Table 1, respectively. The diameter D_{front} = 38.2 mm and the slot exponential geometry is given by $w(l) = w_0 \exp\left(\frac{l}{C_0} \right)$.

TABLE I - ANTENNA PARAMETER VALUES IN MILLIMETERS.

D_s	L_{out}	L_{in}	W_s	L	W_0	C_0
35.91	21.62	14.58	2.69	26.96	0.18	7.55

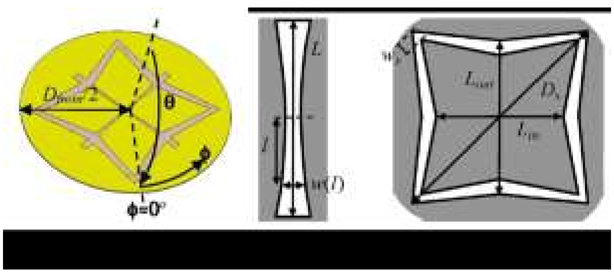

Figure 1 - XETS antenna geometry: (a) front face; (b) exponentially tapered slot; (c) star slot (taken from [15]).

III. LOCALIZATION ALGORITHM

The objective is to identify the location of a target based in indirect measurements (s parameter). According to these results, the Kirchhoff migration algorithm "migrates" the information from the domain of variation observed to the spatial domain in order to estimate the location of the target, as illustrated in Fig. 2.

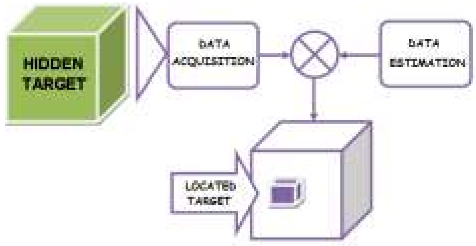

Figure 2 - Kirchhoff migration process.

The Kirchhoff Migration algorithm starts with an estimation grid, equivalent to the hidden target search volume. Then, it estimates what would be the output, in the acquired data domain, for this virtual setup if the target is located in a given point of the grid. The estimation is repeated for every single point of the virtual grid. After that, the estimated results are compared with those measured. If the distance of the estimated point matches the distance of the hidden target, then an increment is made into the result. The accumulation of increments in the same position indicates the location of the target [16].

The signal is transmitted and received by the same antenna (monostatic setup), and the target acts as a possible scattering obstacle from the transmitted wave [17]. The antenna is placed in several locations in the antenna plane and in each location the s_{11} parameter is measured, as illustrated in Fig. 3.

The transmitted wave propagates in the medium until be scattered by the supposed target. The scattered wave is measured at the antenna port location. Once the target is placed at a distance d_{target} from the antenna, the total path (from the antenna to target and from the target to antenna) is $2d_{target}$.

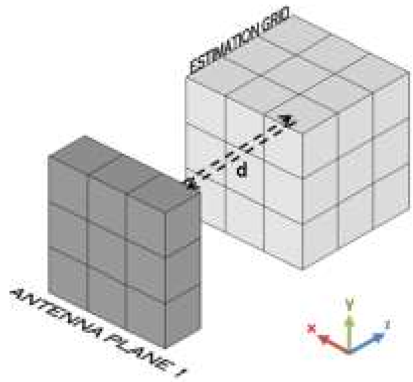

Figure 3 - Kirchhoff Migration Bistatic Representation.

To create the estimated data set, the vector distance from each antenna location ($P_{Ant\_x(i,j)}$, $P_{Ant\_y(i,j)}$, P_{Ant_z}) to each point of the virtual grid ($G_{x(m,n,p)}$, $G_{y(m,n,p)}$, $G_{z(m,n,p)}$) is calculated, using (1),

$$d_{scan(m,n,p)(i,l)} = \sqrt{D_x^2 + D_y^2 + D_z^2} \qquad (1)$$

where $D_x = P_{Ant\_x(i,j)} - G_{x(m,n,p)}$, $D_y = P_{Ant\_y(i,j)} - G_{y(m,n,p)}$ and $D_z = P_{Ant\_z(i,j)} - G_{z(m,n,p)}$

The phase compensation of the reflected wave is obtained when the estimated signal phase equals $e^{+jk2dscan}$.

At each point of the estimation grid there is field with amplitude values proportional to the localization of a target. In the presence of a target, when the distance between the transmitting antenna and a point of estimation grid of localization (d_{scan}) equals the distance from the antenna to the target (d_{target}) occurs a phase cancelation and the amplitude is maximum.

The phase compensation in each grid point is calculated by (2)

$$E_{(m,n,p)} = \sum_r \left| \sum_{i,j} E_0 e^{2jk_r d_{scan(m,n,p)(i,j)}} s_{11(i,j)} \right| \quad (2)$$

where r is the index of frequencies, s_{11} is complex and *(i,j)* is the index of the antenna position.

The Kirchhoff migration method calculates the distance between each point of the grid and all antenna positions for all tested frequencies [18], [20].

In the scope of this work, the phase of the s_{11} parameter is used to indirectly estimate the distance d_{target}. The ratio between the reflected field $E_{(m,n,p)}$ and the incident E_0 is related to the measured complex-valued s parameter.

The propagation constant k is given by (3)

$$k = \omega\sqrt{\mu\varepsilon} = \sqrt{\mu_0\varepsilon_0\varepsilon_r} = \frac{\omega}{c}\sqrt{\varepsilon_r} \quad (3)$$

where ε_r is the permittivity of the medium, in this case $\varepsilon_r = 1$.

In microwave imaging, in measurements and simulations, the realization of a calibration procedure is necessary. The desired scattered signal from target and the unwanted antenna reflection characteristics are both present in the simulated data. Thus, in order to isolate the desired signal, it's necessary to subtract the antenna reflection characteristic from the simulated data. This procedure is called calibration. To isolate the desired data it is calculated the difference between the s parameter of the scenario with the target and the s parameter of the scenario without the target according to (4)

$$s_{11(i,j)} = s_{11\_data(i,j)} - s_{11\_calibration(i,j)} \quad (4)$$

where $s_{11\_calibration}$ and s_{11_data} are obtained by simulation in this paper.

IV. The Target Identification Monostatic Process

The imaging from microwave systems can be implemented in monostatic, bistatic or multi-static configurations. In monostatic mode the same antenna transmits and receives the reflected waves from the target. In bistatic mode there is a transmitting antenna and a receiving antenna which captures the reflected waves from the target, and may or not be coplanar to the transmitting one [21].

The scenario consists of a metallic spherical target with 2 cm of diameter surrounded by air and a single antenna transmit\receive. The simulation is implemented over 1001 frequencies (the frequency interval considered is between 3.1 and 10.6 GHz). The simulation is performed using the CST Microwave Studio simulator, thus the parameter s_{11} is obtained. It used a XETS antenna, as illustrated in Fig. 4.

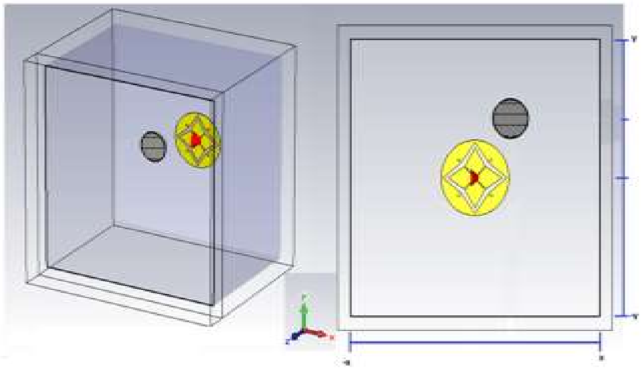

Figure 4 – Monostatic configuration.

V. Results and Discussions

The antenna is scanned between -10 ≤ X ≤ 10 cm and -10 ≤ Y ≤ 10 cm , and Z = 0, with 7 positions (a total of 49 simulated points). The target consist of a metallic sphere with 2 cm of diameter, it is located at coordinates (2, 3, 10) cm. The result is presented in Figure 5, with slices in z-plane.

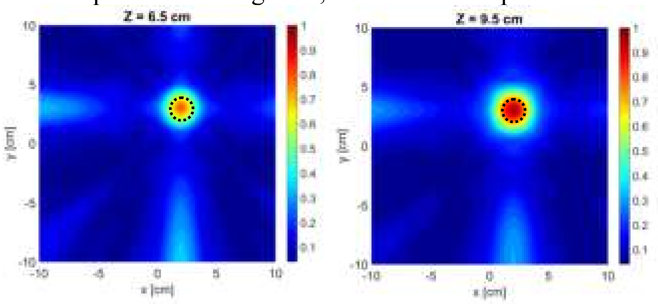

Figure 5 - Two-dimensional slices of z (s_{11} parameter).

In the Figure 5 it is possible to observe a position shift in the target detection. The slice z = 10 cm does not have the highest intensity, but it happens in the slice z = 9.5 cm. At z ≤ 6.5 cm there is no reflection of the target.

In the Figure 6 the antenna moves between -10 ≤ X ≤ 10 cm, -10 ≤ Y ≤ 10 cm, and Z = 0, with 11 positions (a total of 121 points simulated). The position target is the same of the first setup.

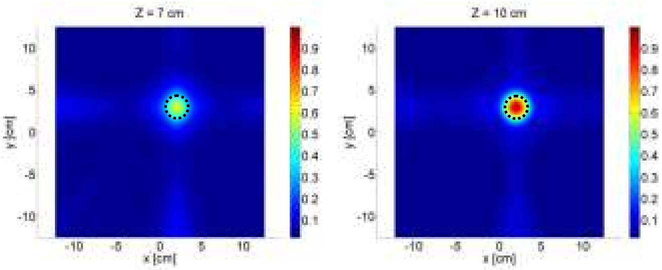

Figure 6 - Two-dimensional slices in z (s_{11} parameter).

In the slice at z = 10 cm the result of the reflection is maximum. At $z \leq 7$ cm there is no reflection of the target. It is perceived also that the resolution of the images is better, obviously due to the increased number of the antenna positions.

In the monostatic mode the quality of image depends of the number of antenna positions, noted by a decrease of artifacts (traces of the image). It is possible also to verify that position detection of the target is more precise, with the increase of the number of antenna positions.

VI. Conclusions

In this work, the target detection using UWB radar technique was studied, using the Kirchhoff migration algorithm and the wideband antenna XETS. The preliminary results with a metallic spherical target are presented. The target was well identified in the point (2, 3, 10) cm.

Despite the difference in the materials of the target and surrounding medium, the procedure is the same as that used for phantoms that mimics the tissue and tumor. In future works, the target will consist of material with dielectric properties that mimics the tumor.

The use of microwave imaging as a first screening test is a safe and non-ionizing alternative to decrease the amount of screening tests involving X-ray.

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