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Citation: Elsdon, Michael, Fdo, Michael J., Leach, Mark and Smith, Dave (2010) Breast cancer detection using microwave holography. In: 7th International Symposium on Communication Systems Networks and Digital Signal processing (CSNDSP), 21-23 July 2010, Northumbria University, Newcastle upon Tyne.

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Breast Cancer Detection using Microwave Holography

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Abstract**— Breast cancer is one of the most common forms of cancer in women. X-ray mammography is the most widely used technique for early detection but has limitations. In this paper, an alternative approach for breast cancer detection using microwave imaging is presented. This is based upon microwave indirect holographic approach, central to which is the use of a synthetic reference beam. This approach has benefits in terms of simplicity and expense. Experimental results using a simple breast phantom are included to demonstrate the potential of this approach.**

Keywords: Holography; breast cancer detection; microwave holography; microwave imaging; image reconstruction; holographic recording.

I. INTRODUCTION

Breast cancer affects many women, and early detection and timely medical intervention are the key to long term survival and life quality for patients [1]. The current gold-standard for medical imaging of breast cancer is the X-ray [2]. However, this screening tool has a number of disadvantages. These include missing approximately 10-30% of breast cancers [3], whilst concerns have also been raised about the high number of false positives [4,5]. A further disadvantage of X-ray mammography is the difficulty in imaging women with dense breasts [6]. Moreover, the ionizing properties of X-rays restricts the frequency of screening.

These limitations motivate the search for new methods of breast tumour detection. Other established diagnostic techniques such as breast ultrasound and MRI, which do not expose the patient to ionizing radiation are also used for breast cancer detection. Breast ultrasound is considered to be the appropriate modality for the initial evaluation of a palpable breast mass in pregnant women and for evaluation of a palpable breast mass in a women under the age of 30 [7,8]. Breast ultrasound also has some limitations, which include relatively higher cost compared with mammography; operator-skill dependency; and the time required to carry out the study. Perhaps the biggest disadvantage of this modality is its higher false negative rate, when compared to mammography, for general screening. MRI has been shown to be effective in screening women with increased risk of breast cancer. Advantages of MRI include detection of small cancers; use of non-ionizing radiation; and its effectiveness in imaging dense breast tissue that is characteristic of pre-menopausal women. Disadvantages of this technique include restricted availability and low specificity. Moreover, this technique is much more expensive than X-ray mammography.

Microwave imaging of breast tumours offers an alternative method of breast cancer detection and has been the subject of much study. X-rays detect structural changes in tissue cells whilst microwaves detect changes in dielectric properties, which occur before structural changes. Hence microwave imaging can potentially offer an earlier detection of cancer. Several microwave imaging techniques have been suggested, including microwave tomography and confocal imaging. The majority of these approaches are based on the use of pulsed techniques where the location of the tumour is obtained by processing data in the time domain.

It has recently been reported that an indirect holographic technique can be used to reconstruct the complex aperture field of an antenna from a single scalar intensity pattern [9]. This work has been extended to provide detection of metallic objects for use in security screening [10]. In this paper, it is shown how this technique can be extended for early stage breast cancer detection. Experimental results using a simulated phantom are included to demonstrate the potential of this approach.

II. DIRECT HOLOGRAPHY

The use of Direct Holography for the determination of antenna radiation patterns and imaging of aperture fields has received much attention [11-16]. The same technique can also be adapted to reconstruct 3D images of objects from complex near field measurements. For the imaging of objects, a complex field pattern, $E(x,y)$, is recorded over a 2D aperture located at a distance, $z = d$, from the object. Performing a fourier transform on this field converts the data to a plane wave spectrum, $A(k_x,k_y)$.

$$A(k_x,k_y) = F\{E(x,y)\} = \frac{1}{2\pi}\iint E(x,y)e^{-j(k_x.x+k_y.y)}dxdy \tag{1}$$

Assuming that the original coordinate system is located at the plane of the scanning aperture, z = 0, the complex scattered field at the plane, E (x,y, z = d), can be obtained using a back-propagation approach [28].

$$E(x, y, z = d) = \frac{1}{2\pi} \iint A(k_x, k_y) e^{jk_z.d} e^{-j(k_x.x+k_y.y)} dk_x.dk_y \tag{2}$$

where

$$k_z = \sqrt{k_0{}^2 (k_x{}^2 + k_y{}^2)} \tag{3}$$

III. INDIRECT MICROWAVE HOLOGRAPHY

Indirect holographic imaging consists of two stages: the recording of a sampled intensity pattern and image reconstruction. The off-axis hologram was first introduced by Leith and Upatnieks [10] for the recording of optical wavefronts. In the recording stage, an intensity pattern is formed from the interference pattern between the scattered wavefront and a coherent plane wave, introduced at an offset angle to the recording plane. This is illustrated in figure 1.

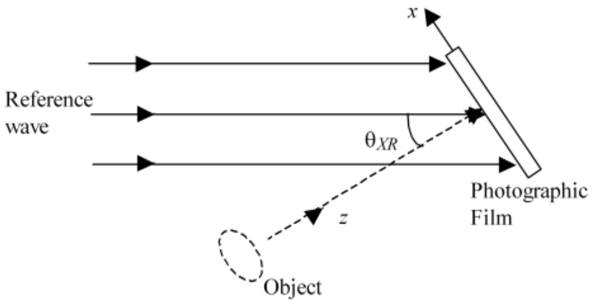


Figure 1: Off-axis Hologram

The adoption of this technique at microwave frequencies has proved difficult due to the practical problems associated with providing an offset reference wave. A technique to overcome this problem has recently been described [9].

The basis of this technique is to replace the offset radiated reference wave by an electronically synthesized reference wave. This is derived by tapping off a fraction of the signal used to illuminate the object using a directional coupler. The phase of this signal is controlled by varying the phase shifters under computer control. To form an intensity pattern, the reference signal is combined with the scattered signal of the object. An diagrammatic representation of this arrangement is shown in figure 2.

The measurements are taken over a regular rectangular grid spaced at λ/2, with a linear phase increment introduced by the variable phase shifters as the circulator moves in the x direction.

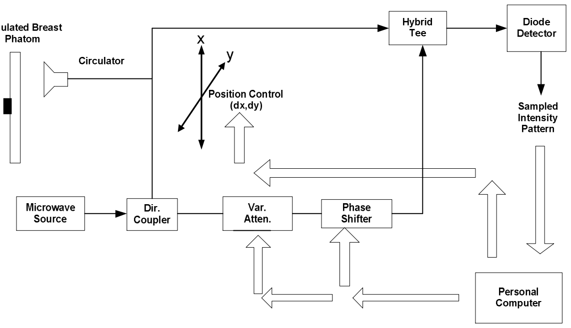


Figure 2: Experimental Arrangement for Intensity Pattern Formation

The form of the resultant intensity pattern is given by:

$$I(x, y) = |E(x, y) + R(x, y)|^2$$

$$= |E(x,y)|^2 + |R(x,y)|^2 + E(x,y)R^*(x,y) + E^*(x,y)R(x,y) \tag{4}$$

where *E(x,y)* represents the complex scattered field over the *x,y* plane, *R(x,y)* represents the complex field of the reference wave over the (*x,y*) plane and * denoted complex conjugate. If the reference wave is introduced along the x axis, it takes the form:

$$R(x, y) = E_0 e^{-jk_x x} \tag{5}$$

$$R^*(x, y) = E_0 e^{-jk_x x} \tag{6}$$

The first stage in the process to reconstruct a high quality image of the original object is to take the Fourier Transform of this intensity pattern (4) to obtain a pattern in the spatial frequency domain (7).

$$F\{I(x, y)\} = F\left\{|E(x, y)|^2\right\} + F\left\{|R(x, y)|^2\right\}$$

$$+ F\{E(x,y)\} \otimes F\{R^*(x,y)\} + F\{E^*(x,y)\} \otimes F\{R(x,y)\} \tag{7}$$

Provided that the spatial frequency of the scattered object is band limited and a sufficient phase shift can be applied to the reference wave, the four components in (7) can be separated into three regions. This is shown diagrammatically in figure 3.

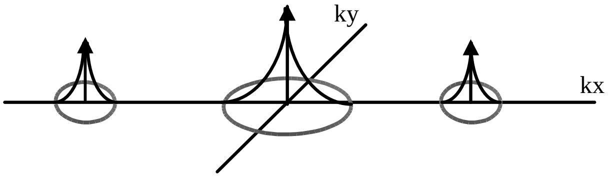


Figure 3: Spectral representation of an off-axis hologram

The first two terms of equation (7) correspond to the auto-correlation of the scattered object wave and the reference wave respectively. These components appear in the centre of the spectrum as a result of their DC content. The third and fourth terms of equation (7) relate to the convolution of the reference wave with the scattered wave and it’s complex conjugate. These are offset from the origin by an amount related to the angle of the reference wave and contain sufficient information to reconstruct the image. The use of a synthesised offset reference plane wave allows the third and fourth terms of equation (7) to be separated in the spatial frequency domain. The next stage in the reconstruction process is to filter off the unwanted terms and centralise the required term to give the plane wave spectrum of the original object:

$$F'\{(x,y)\} = E_0.F\{E(x,y)\} \qquad (8)$$

Taking the inverse fourier transform of (8) gives the original scattered field of the object at the measurement plane, z = 0:

$$G\{F'\{I(x,y)\}\} = E_0.E(x,y) \qquad (9)$$

A focused image of the object at different distances can be obtained by back-propagating the PWS of the object (8) through the desired distance, z = d [17]. This particular step follows the same approach to that described for direct holography (eqn. 2).

IV. EXPERIMENTAL RESULTS

To demonstrate the ability of this technique to produce good quality images, a modified breast phantom has been adopted. Winters et al [18] recently reported that the dielectric properties of skin, normal breast fat and tumour have dielectric constants of approximately 10, 30 and 50 respectively. To simulate this, a breast phantom with a similar ratio of skin: fat: tumour has been adopted. In this experiment, the measurements are performed in free-space, with a block of wood, and sheet of polyvinyl chloride (PVC). This is shown in figure 4. The dielectric properties of materials were confirmed by measurements taken using a Agilent E8364B PNA Network Analyser and Agilent 85070E dielectric probe kit.

Results have been taken at a distance of 5cm from the simulated tumour at a frequency of 10GHz over a scanning aperture 72cm x 72cm, with a sample size of 1cm. The reconstructed image is shown in Figure 5 together with an outline of the original object for comparison. It can be seen that good correlation has been achieved between the original object and the reconstructed image.

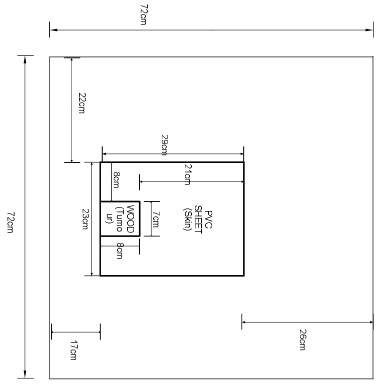
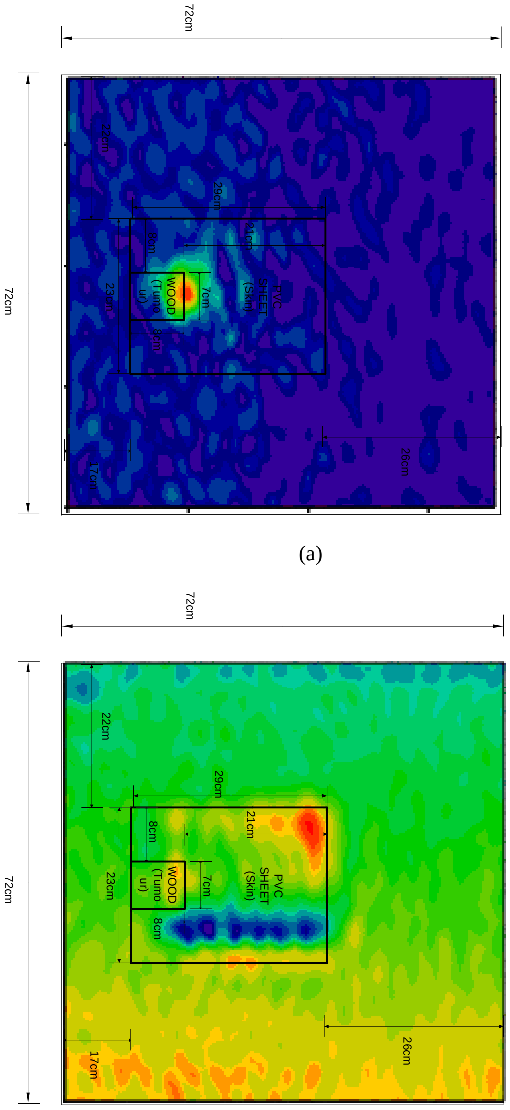


Figure 4. Simulated breast phantom



(a)

(b)

Figure. 5: Reconstructed (a) Magnitude and (b) phase images

V. CONCLUSION

A technique for the detection of breast cancer based on a novel indirect holographic technique has been demonstrated. Practical results have shown that this technique is successful for determining both the location and shape of the simulated tumor. The use of this approach offers considerable benefits in terms of simplicity and expense when compared with other microwave imaging techniques.

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