Accuracy Enhanced Beamforming Method Based on Envelope Surface Extraction for Non-contact UWB Breast Cancer Radar

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Abstract - **Microwave UWB (Ultra Wideband) radar is promising as a non-invasive medical imaging, such as breast cancer or brain stroke detection due to its non-ionizing feature and deeper penetration ability in low loss medium. While various methods for specifying the breast cancer detection issue, have been developed, most of them require a prerequisite that a shape of breast surface is accurately determined or sensor should be contacted to breast surface. To solve this problem, this paper introduces the surface clutter suppression using the Envelope boundary extraction method and FDTD based signal regeneration. In addition, this method revises an original beam-forming algorithm by compensating the propagation path distorted into breast. The results in numerical simulation show that our proposed method effectively suppresses the surface clutter and**

Index Terms — **Microwave breast cancer imaging, Surface clutter suppression, Non-contact measurement, Envelope.**

1. Introduction

According to recent statics from the Japanese ministry of health, labor and welfare, the breast cancer is the top diagnosed cancer type among women in Japan. While X-ray mammography is a present primary screening technique for detecting tumor in early-stage, there are some disadvantages for highly compressed measurement being painful for subjects, high rate for false-negative (10-30%) or false-positive (more than 70%), reported in [1]. In recent decade, an intensive researches for microwave UWB (Ultra-Wideband) radar have been developed, because a lower frequency microwave has a non-ionizing effect, less lossy and deeper penetration ability. The most significant advantage of this radar is that it is recognized as substantial contrast in the dielectric properties between normal and malignant tissues [2]. By exploiting great contrast, various refocusing methods aiming at breast tumor localization, have been developed, such as space and time beamformer method known as MIST (Microwave Imaging via Space-Time) beamforming method [3], or inverse scattering approach such as DBIM (Distorted Born Iterative Method) or multiple non-linear optimization schemes. Focusing on MIST algorithm, a strong echo from breast surface regarded as clutter, efficiently is eliminated by correcting FIR filter responses of different sensor locations. Then, delay and sum processing, which compensates the frequency dependency of dielectric properties of each tissue, has been introduced to localize the cancer. While the effectiveness of this method has been verified in many reports, it requires the assumption that the antenna should be contacted to breast surface to eliminate surface clutter or retain refocusing accuracy. However, in actual scenario, it is not so easy to fit the sensor to breast surface depending on subject. Even in succeeding fitting, the preliminary estimation for spatial distribution of sensors is needed to maintain the accuracy of beamforming result. While there are some studies for non-contact measurement approach, incorporating surface boundary extraction scheme, [4]. there are not enough investigations for possibility of suppressing surface clutter or accuracy enhancing of beamforming result exploiting boundary information. This papers introduces the Envelope method for breast surface extraction and elimination of surface clutter, which are regenerated by FDTD. In addition, this paper modifies the original beamforming algorithm by considering the distorted propagation path, which are accurately calculated by employing normal vector on surface estimated by Envelope [5]. Results in numerical simulation show the effectiveness of our proposed method.

2. System Model

Figure 1 shows the system model. A mono-static radar is scanned along a circular orbit surrounding breast surface. It is assumed that a breast and tumor have homogeneous, lossy, non-dispersive and isotropy property. $s(X,Y,R)$ is defined as the output of the Wiener filter, where the transmitting and receiving antenna is located at $(x,y) = (X,Y)$, and $R = ct/2$ is expressed using time t, and c is the speed of light. Range points are extracted from the maxima of $s(X,Y,R)$, which are defined as $\boldsymbol{q} = (X,Y,R)$.

3. Proposed Method

For the sake of suppressing surface clutter or enhancing beamforming accuracy, this paper introduces a breast surface extraction method as Envelope method [5]. This method is based on principle that surface boundary is expressed as outer envelope of circles (ellipses in multi-static), with center (X,Y) and radius R. Then, by collecting range points $\boldsymbol{q}$, the breast surface can be extracted by this method. The notable feature of this method is that it accurately obtains not only boundary point but also its normal vector, because normal point is directed to line of sight direction, which is determined by

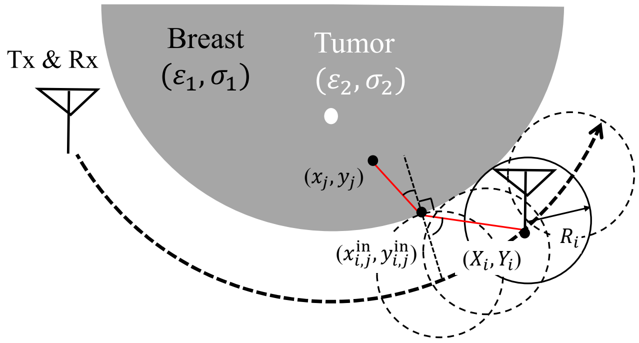

Fig. 1. System model and Extended DAS principle considering distorted propagation path.

relationship between scattering center and its antenna location associated with Envelope. Using the extracted surface shape and location, surface reflection signals are regenerated by FDTD method, where the dielectric properties of breast are referred from its typical reported values. These signals are subtracted from the observed signal $s(X, Y, R')$, where time and amplitude jitter is eliminated through normalization and cross-correlation based registration. The subtracted signal after such compensation is denoted as $\tilde{s}(X, Y, R')$.

Next, the original beamforming method is modified, considering a distorted path over breast surface. The possible propagation path to each pixel is determined for locating the incident point on surface, so that the Snell's law should be satisfied among antenna location, incident point and targeted pixel. For this calculation, we exploit the notable feature that the Envelope directly offers normal vector on its boundary point, as mentioned before. The optical path length $R_{i,j}$ between antenna location (X_i, Y_i) and image pixel (x_j, y_j) through an incident point $(x_{i,j}^{in}, y_{i,j}^{in})$ is determined as;

$$R_{i,j} = \|(X_i, Y_i) - (x_{i,j}^{in}, y_{i,j}^{in})\| + \sqrt{\epsilon}\|(x_{i,j}^{in}, y_{i,j}^{in}) - (x_j, y_j)\|, \quad (1)$$

where $\| * \|$ denotes Euclidean norm, and ϵ is assumed dielectric constant. The reconstruction image $I(x_{i,j}, y_{i,j})$ by modified beamforming is denoted as;

$$I(x_{i,j}, y_{i,j}) = \sum_{i=1}^{N} \tilde{s}(X_i, Y_i, R_{i,j}), \quad (2)$$

Figure 1 shows the principle of modified beamforming method using boundary obtained by Envelope method.

4. Evaluation in Numerical Simulation

This section describes the effectiveness of our proposed method through FDTD based numerical simulation. The transmitting signal is Gaussian modulated pulse, whose center frequency is 5.0 GHz, and 10 dB bandwidth is 3.75 Hz. Homogeneous breast medium with dielectric constants and conductivity (ϵ_1, σ_1) = (4.5, 0.13[S/m]) is assumed, while a point-wise malignant tumor with (ϵ_2, σ_2) = (54, 5.0[S/m]) is buried in this medium. A set of transmitting and receiving antennas is scanned along the circumference of circle, where the gap between breast and its orbit is set to 0.5λ and is sampled at 40 discrete points with the fixed interval. Figure 2

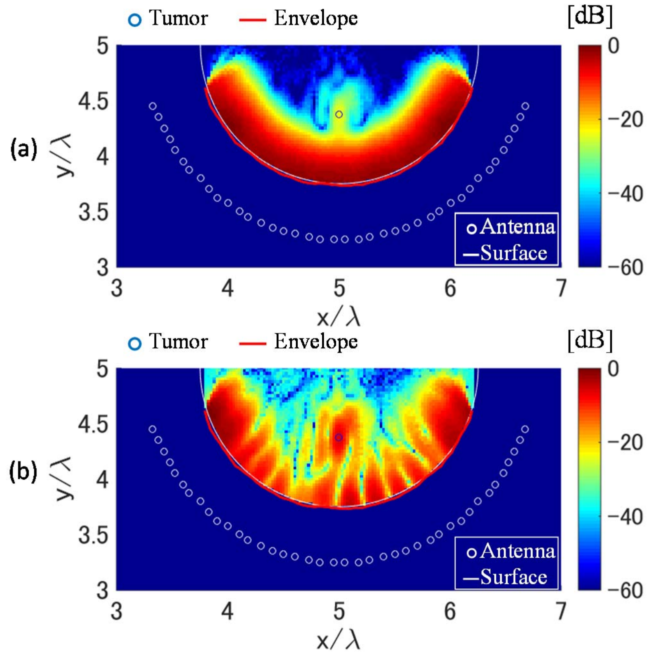

Fig. 2. Focused image by modified beamforming, ((a): before and (b) after surface reflection suppression.

shows the reconstructed image before and after suppression of surface reflection signals by the proposed method. Here, in data regeneration by FDTD, we give 10 % relative errors for dielectric properties. SCR (signal to clutter ratio) is upgraded from −23 dB to −5 dB by suppressing surface reflection, where power of clutter is maximum power observed along the breast surface. In addition, the cancer location is accurately located by compensating propagation distortion by exploiting the Envelope feature. An incomplete suppression is derived from mismatching between actual and estimated surface reflection wave, which is caused by the imaging error of Envelope or the error of assumed dielectric constant.

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