Accurate Breast Surface Imaging Method with FDTD-based Waveform Correction for Microwave Mammography

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***Abstract*—Microwave mammography is promising alternative from X-ray based imaging modality, in terms of compactness, low cost and cell-friendly exposure. The most important part of this modality is a suppression of surface reflection clutters, which can be enhanced by combining accurate surface shape estimation. The coupling effect between antenna and breast surface degrades accuracy in the shape estimation, which is caused by a mismatch between reference and observed waveform. To solve this problem, this paper incorporates the Envelope-based shape estimation and FDTD-based waveform correction with a fractional derivative adjustment. Numerical simulation based on realistic breast phantom derived from MRI show that our proposed method significantly enhance the accuracy for breast surface imaging and the SCR (signal to clutter ratio) by suppressing a skin reflection.**

***Key words*—Microwave ultra wide-band(UWB) mammography, Envelope method, FDTD-based waveform correction.**

I. INTRODUCTION

According to world cancer research fund(WCRF), the breast cancer is the top diagnosed cancer in women worldwide. While the X-ray mammography is representative screening technique for detecting malignant tumor, it requires a cell-harmful exposure and highly compressed measurement for human breast, which causes an insufficient participation rates, especially for young women. A ultrasound-based imaging modality enables safe and harmless investigation, but it requires a contact measurement and its detection accuracy largely depends on the skill of the operator. On the contrary, microwave ultra-wideband(UWB) mammography has a number of advantages from the existing techniques, such as portability, non-contact and cell-friendly measurement, and low cost. Many investigations and studies have revealed that there is a significant contrast in the dielectric properties between normal (typically adipose) and malignant tumors. This electric contrast triggers a development for microwave mammography, and there are various imaging algorithms for cancer, such as beamforming (delay and sum (DAS))[1], or tomographic approaches[2].

To generate high contrast image for malignant tumor, any method requires an efficient elimination of skin reflection components, which is considerably stronger than that of tumor response. The number of studies mostly employ an average measured reflection signal with suitable time-gating[1] as skin reflection, however, this kind of method has a risk for suppression of targeted tumor response. The method[3] introduces the Envelope-based shape estimation and the FDTD-based reflection signal generation to solve this problem, but waveform reconstruction accuracy largely depends on that of prior estimation of breast surface boundary. Generally, due to the coupling effect between antenna and skin surface, the skin reflection waveform mismatches to the reference one, which causes a non-negligible error in the matched filter based range estimation. Thus, this paper proposes the FDTD based waveform correction scheme for more accurate breast surface imaging, which is achieved by Envelope method [4]. Further suppression of skin surface reflection, this method also introduces a fractional derivative adjustment of the regenerated signal by the FDTD method. The numerical simulation results, using the MRI-derived realistic breast phantom, demonstrate that our proposed method considerably enhances the SCR, even in heterogeneous case.

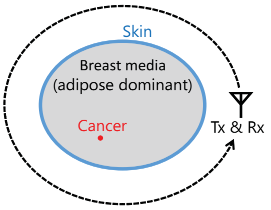

Fig. 1: Observation model.

II. SYSTEM MODEL

Figure 1 shows the system model. A mono-static radar is scanned along orbit surrounding breast surface. It is assumed that a breast medium consists mainly of skin, fat and fibroglandular, and each medium is assumed to be lossy, dispersive and isotropic. $s(X, Y, t)$ is defined as the output of the matched filter, where the transmitting and receiving antenna is located at $(x, y) = (X, Y)$ and time t.

III. PROPOSED METHOD

Although there are a number of methods for skin reflection suppression in the literature [1], these methods mostly employ the average of measured signals to calculate a skin reflection signal, which includes cancer responses. To avoid the over-suppression, the method [3] introduces the FDTD based calculation for skin reflection, by using a prior shape estimation of skin surface by the Envelope method [4]. However, the suppression performance of this method largely depends on the accuracy in the surface shape estimation. In the near-field observation, an accurate distance measurement from antenna to skin surface is hardly achieved, because a coupling effect causes a waveform mismatches between the measured and reference (usually assuming the transmitted signal including only radiation electric field).

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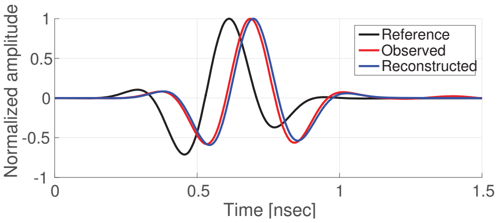
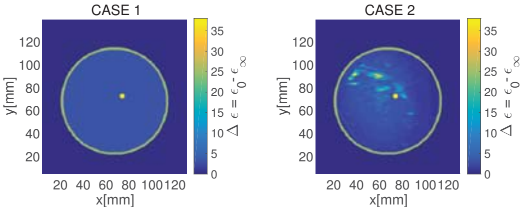


Fig. 2: Comparison of reference, observed and FDTD-reconstructed waveforms.



(a) (b)

Fig. 3: The map of the Debye parameter $\Delta\epsilon$ ((a): CASE 1: homogeneous and (b) CASE 2: heterogeneous (MRI-derived)).

To overcome this difficulty, this paper proposes more accurate shape estimation algorithm, using the FDTD-based waveform correction and suppression. Here, $\hat{s}(X,Y,t)$ is denotes the skin reflection signal estimated by the FDTD method, with a prior estimation of skin surface using the Envelope method. $\hat{s}(X,Y,t)$ includes the coupling effect between skin and antenna, and then, it forms more similar waveform, compared with the preliminary assumed reference signal. Figure 2 shows a comparison of reference waveform and measured and estimated skin reflections. Then, the distance between skin surface and an antenna location denoting $\tilde{R}$ is updated as;

$$\tilde{R} = \hat{R} + c\Delta\tau/2, \tag{1}$$

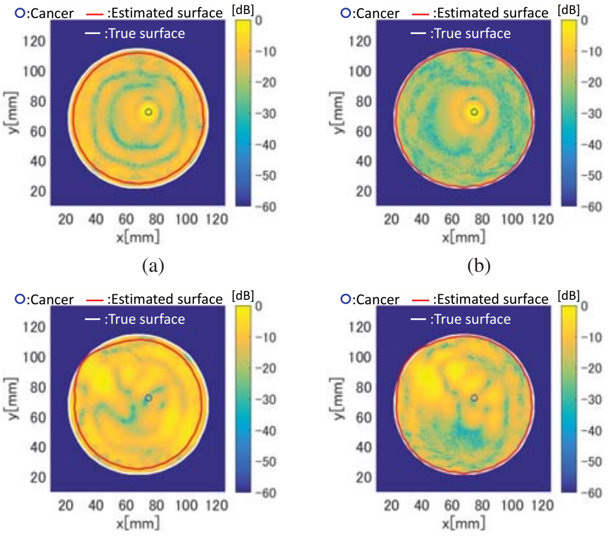
where $\hat{R}$ denotes the initially estimated distance using the reference signal, and $\Delta\tau$ is calculated as;

$$\Delta\tau = \arg\max_{\tau}[s(X,Y,t) \star \hat{s}(X,Y,t)](\tau), \tag{2}$$

where $\star$ denotes the operator of cross-correlation.The boundary of breast surface is updated by the Envelope method using the corrected distance $\tilde{R}$. Next, the skin reflection signal is suppressed by the updated estimation signal by FDTD. For more effective suppression, this method introduces a fractional derivative based waveform adjustment of the FDTD-estimated signal. Namely, by introducing the parameter α, the adjusted signal is expressed as $\hat{s}(X,Y,t,\alpha) = \mathcal{F}^{-1}\left[(j\omega)^{\alpha} S(X,Y,\omega)\right]$, where $S(X,Y,\omega) = \mathcal{F}[s(X,Y,t)]$ and $\mathcal{F}$ denotes the Fourier transform operator. By adjusting a delay, amplitude and α, the skin reflection signal is suppressed with $\hat{s}(X,Y,t,\alpha)$. Finally, the DAS image is obtained by the subtracted signals, which is detailed in [3].

IV. TEST WITH NUMERICAL BREAST PHANTOM

We test our method using simulated measurements of realistic breast phantom derived from MRI of healthy women [5]: a Class 2 (Scattered Fibroglandular) phantom (IDnumber 010204). TE(transverse electric) wave is assumed. The transmitting signal forms the raised-cosine modulated pulse, whose center frequency is 2.45 GHz, and bandwidth is 2.7 GHz. The frequencydependent complex permittivities for breast phantoms are modeled by the single-pole Debye models. To reveal the feature of this method, the homogeneous (except for skin) called CASE1, and heterogeneous (MRI-derived) cases, called CASE2, are investigated as shown in Fig. 3, denoting the map of the Debye parameter $\Delta\epsilon$, that is the difference of relative permittivity from zero to infinite frequency. Figure 4 shows the estimated breast surface and the DAS image for each CASE and method. Table I summarizes the results for RMSE (Root Mean Square Error) of surface shape estimation and SCR. Figure 4 and Table I show that the RMSE and SCR are considerably enhanced by the proposed method. Note that, in the heterogeneous case, a high contrast fibroglandular tissue generates a significant response in DAS image, which should be resolved by enhancing the contrast using contrast agents in malignant tumor.



(a) (b)

(c) (d)

Fig. 4: The estimated breast surface and the DAS image (a): the conventional method and (b): the proposed methods in CASE 1. (c): the conventional method and (d): the proposed method in CASE 2.

TABLE I: RMSE and SCR for each method.

	Medium	Conventional[3]	Proposed
RMSE[mm]	CASE 1	2.1	0.67
	CASE 2	2.7	0.81
SCR[dB]	CASE 1	10.7	16.5
	CASE 2	-9.3	-5.37

ACKNOWLEDGEMENT

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