Frequency Domain Artifact Removal Technique for Multistatic Microwave Head Imaging

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Abstract — **Microwave techniques have the potential to be used for head imaging to detect brain abnormalities. However, the outer section of the human head, which consists of different tissue layers, such as skin, skull, fat and muscles, presents a strong signal reflections and scattering clutter that might mask the target's response. In addition, those reflections tend to persist over a long duration of time, due to the multilayer structure of the head. These artifacts debilitate microwave imaging algorithms to successfully detect brain injuries inside the head. In this paper, a hybrid artifact removal method which combines the entropy-based filtering and differential approach, is presented to remove those artifacts in multistatic microwave head imaging. In this method, an entropy-based filter separates strong reflections from other signals, whereas the differential approach removes the artifacts from those reflections at different frequency samples. The proposed approach is successfully tested using realistic multilayer head model and an 8-element antenna array.**

Keywords — Microwave imaging; head injury detection; clutter removal; frequency domain

I. Introduction

Signal processing techniques are important element of any microwave imaging system for medical applications [1]-[2]. Those systems are designed to enable the detection of abnormalities, such as injuries, cancers etc., inside the human body. The physical basis of processing techniques in microwave imaging is the significant difference between the dielectric properties of healthy and unhealthy tissues. Those differences change the magnitude and phase of backscattered signals. However, the strong backscatter from the outer layers of any imaged object are usually stronger than the signals emanated from the target (tumor/injury), especially in early detection cases. Thus, to get any meaningful images, those outer-layer reflections, as artifacts, should be eliminated using proper processing techniques [3]-[8].

In microwave head imaging, the backscattered signals consist of multiple reflections from the skin, skull, fat and muscles around the brain. Eliminating these artifacts is more complex than removing a single layer artifact, because multiple reflections cannot be isolated from other components of the received signal by using, for example, a simple time windowing method [3]. The disparate dielectric properties of different layers of the head trap electromagnetic modes inside those layers, and thus establish a time delay in the reflected signals [9]. This delay causes the reflections to overlap with the target's signal. Therefore, a novel approach is required to overcome the aforementioned problem.

In this paper, a frequency-based hybrid artifact removal technique, which is based on using the combination of entropy-based filtering and differential approach, is presented. The simulated results indicate that the proposed method strongly reduces the artifacts in multistatic microwave head imaging.

II. Proposed Method

In recent years, various methods are proposed in literature to remove the skin artifact in microwave medical imaging [3]-[7]. However, those methods are mainly developed for breast imaging, in which the multiple reflections and time overlapping is not a case. In this paper a hybrid artifact removal technique is proposed, which combines the best aspects of the entropy-based filtering [6] and differential approach [5], to remove or at least mitigate the multiple artifacts in multistatic head imaging. Combining these methods in frequency domain not only addresses the time-overlapping issue, but also the changes in the penetration capability of different frequencies.

It is assumed that N_a antennas surround the imaging domain (head) to provide N_a^2 multistatic data with N_f frequency samples. The sampled waveform transmitted by antenna i and received by antenna j is denoted by $b(i, j, n)$. Target and clutter signals are discriminated using the third order of Renyi entropy (H_3) which is known to be the best entropy for a broad class of signals [10]:

$$H_3(f_k) = -\frac{1}{2}\log\left(\sum_{j=1}^{Na}\sum_{i=1}^{Na}\left[P\left(R_i, T_j; f_k\right)\right]^3\right) . \tag{1}$$

where $P(i, j; n)$ indicates the amount of uncertainty of the data:

$$P(i, j; n) = \frac{|b(i,j;n)|^2}{\sum_{j=1}^{Na}\sum_{i=1}^{Na}|b(i,j;n)|^2} \tag{2}$$

which satisfies $P(i,j;n) \geq 0$ and $\sum_{j=1}^{Na}\sum_{i=1}^{Na} P(i,j;n)$. In this stage, the signals over a tolerance threshold are considered as the clutter:

$$w(i,j;n) = \begin{cases} b(i,j;n) & e^{H_3(n)} \geq N_0 \\ 0 & otherwise \end{cases} \tag{3}$$

where $1<N_0<(N_a)^2$ is the entropy threshold, which is suggested to be half of the number of received signals [6].

Once the high value signals, $w(i,\ j;\ n)$ are defined, the differential approach is applied to remove the artifacts from the strong reflections which contains target's and layer's responses. The artifact is removed by subtracting signals of two symmetrical antenna positions in the left and right side of the head:

$$c(i,j;n) = w(i,j;n) - w(N_a + 2 - i, N_a + 2 - j; n) \tag{4}$$

for $i,j = 1$ to N_a with $N_a + 1 = \frac{N_a}{2} + 1$ for $i,j = 1$ and $\frac{N_a}{2} + 1 = 1$ for $i,j = \frac{N_a}{2} + 1$.

The physical basis of this method is that artifact influences is similar for two symmetric antennas due to the constant thicknesses of the layers in front of those antennas, whilst target reflections have different impacts on each antenna, due to the different distances between the target and each antenna.

Finally, the clutter-dominated samples are replaced by the artifact removed ones:

$$S(i,j;n) = \begin{cases} c(i,j;n) & e^{H_3(n)} \geq N_0 \\ b(i,j;n) & otherwise \end{cases} \tag{5}$$

The artifact-removed signals (S) are then applied to a modified frequency-based algorithm [11] to provide a 2D image, which detect and locate the brain injuries inside the head. The imaging algorithm calculates the intensity of the power, $I(x, y)$ inside the imaging region using Bessel function of the first kind $J_1(k\rho)$:

$$I(x,y) = \left\| \sum_{n=1}^{Nf}\sum_{j=1}^{Na}\sum_{i=1}^{Na} S(i,j,n) J_1^2(k\rho) e^{i2(k\rho+\varphi)} \right\|, \tag{6}$$

where k is the wavenumber inside the imaging domain and (ρ, φ) is the distance and the angle between a transmitter and a receiver by selecting a point-scatterer at (x, y) inside the imaging region.

III. Results

To test the proposed method, the sampled waveforms, $b(i,j;n)$ are captured from a circular antenna array consisting of 8 compact ultra-wideband antennas [12], positioned around a realistic MRI-based head model [13] (Fig. 1). The simulations are performed in CST Microwave Studio environment using the frequency band of 1.1-3.2 GHz with 60 MHz frequency intervals. The head phantom model consists of a multilayer outer structure (skin, skull, fat, and muscle) and other internal tissues such as grey and white matters, CSF, Dura, with their actual electrical properties. A small size of blood is placed inside the model, to emulate the scenario of a brain injured (bleeding) patient.

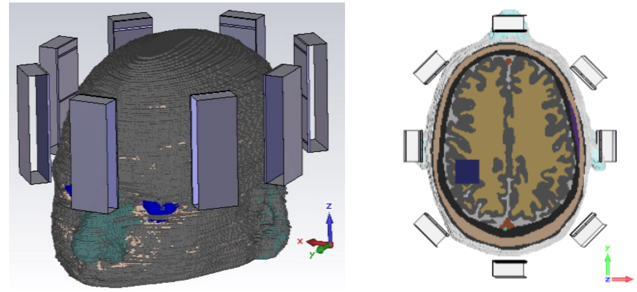

Fig. 1. Simulation setup for microwave head imaging system.

The proposed artifact removal method is then applied to the recorded data and 2D images are then generated by applying preprocessed signals to (6). The obtained images before and after applying the artifact removal technique are shown in Fig. 2. The result in Fig. 2 (a) demonstrate how the target is completely masked by the strong clutter. It is obvious from Fig 2 (b) that the proposed method effectively cancels the outer layer artifacts. However, this method has negligible effect on the target response, as there is a slight error in the localization of the target. This error can be reduced by increasing the number of antennas around the head.

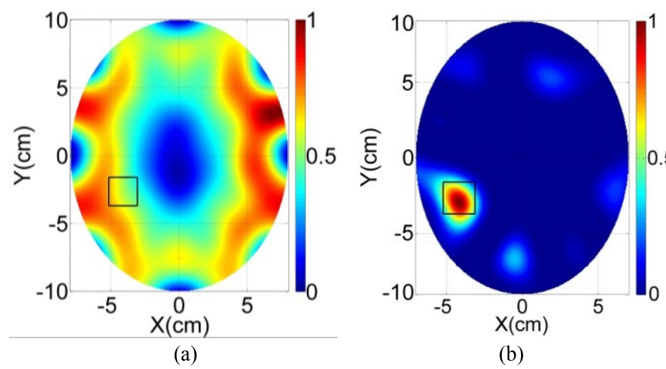

Fig. 2. Reconstructed images (a) without applying artifact removal technique, and (b) after using proposed hybrid method.

IV. Conclusion

A frequency domain hybrid artifact removal algorithm for microwave head imaging has been presented. Due to the multilayer structure of the outer section of the head, the received signals from the head imaging system usually suffer from a time and frequency overlapping that causes false detection when using traditional methods. The proposed method uses the entropy-based filtering to discriminate between the target and clutter components of each frequency sample. The differential approach is then used to remove the artifact-dominant part of the signals originated from the outer layers of the head. The performance of the proposed method has been successfully tested on realistic head model in simulation environment.

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