Biomedical Signal Processing and Control 34 (2017) 93–100

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

# Adaptive artifact removal for selective multistatic microwave breast imaging signals

M.A. Elahi*, M. Glavin, E. Jones, M. O'Halloran

*Electrical and Electronic Engineering, National University of Ireland Galway, Ireland*

ARTICLE INFO

*Article history:*
Received 21 July 2016
Received in revised form 11 January 2017
Accepted 13 January 2017

*Keywords:*
Microwave imaging
Ultra wideband radar
Breast cancer
Multistatic artifact removal
Skin subtraction
Skin-artifact removal

ABSTRACT

Microwave imaging is one of the most promising alternative breast imaging modalities. Early-stage artifact removal is an important signal processing component of a microwave breast imaging system. In this paper, a monostatic artifact removal algorithm is extended to remove the early-stage artifact from multistatic radar signals. The multistatic radar signals exhibit greater variation in the early-stage artifact due to varying propagation paths between transmitting and receiving antennas. This variation makes it more challenging to estimate and remove the artifact compared to the monostatic signals. This paper proposes an entropy-based adaptive method to group signals with similar artifacts and then remove the artifact from each group separately using a hybrid artifact removal algorithm. The efficacy of the proposed algorithm has been demonstrated by imaging anatomically and dielectrically realistic 3D numerical breast phantoms.



## 1. Introduction

Confocal microwave imaging (CMI) systems for breast cancer detection require two stages of processing: early-stage artifact removal and image reconstruction [1]. The early-stage artifact is typically composed of the incident wave, combined with the reflection from the skin-breast interface and some residual antenna reverberation. If artifact is not effectively removed, it could mask any tumours present within the breast. Most artifact removal algorithms remove the artifact from a particular channel by estimating the artifact signal from the other channels. The variation between signals received at other channels greatly affect the ability of algorithm to produce an accurate estimate of the artifact. A comprehensive comparison of early-stage artifact removal algorithms for microwave imaging of breast has been presented in [2]. The main conclusions from the study are that algorithms such as the average and the rotation subtraction method do not work well when there is a variation between channel artifacts. Conversely, filter-based methods are more robust to the variation in between-channel artifacts, but the window containing the artifact must be known *a-priori*. The entropy-based method estimates the window containing the artifact, but often introduces distortion into the tumour response.

A hybrid artifact removal (HAR) algorithm has been proposed in [3], which combines the entropy-based approach and the Wiener filter algorithm to effectively remove the artifact while preserving the tumour response. The HAR algorithm has shown robustness to the variation in the artifacts but it has only been tested in monostatic scenarios. The variation in the monostatic signals is primarily due to the variation in the skin shape and the skin thickness. In contrast, the multistatic signals exhibit greater variation not only due to the varying skin shape and the thickness but also due to the different propagation distance between transmitting and receiving antenna. Most of these artifact removal algorithms have been solely used with monostatic radar signals, with the exception of the rotation subtraction algorithm [4]. However, the rotation subtraction algorithm is specific to the geometry of hardware prototype for breast cancer imaging reported in [4].

In this paper, a novel multistatic artifact removal (MAR) algorithm is proposed. The proposed algorithm extends the HAR algorithm used for monostatic signals [3] to the more challenging scenario of multistatic signals. In the HAR algorithm, the artifact-dominant portion of the signals is estimated using the entropy-based approach and the artifact is then removed by a Wiener filter. In the multistatic artifact removal algorithm, the signals containing similar early-stage artifacts are adaptively grouped together based on the entropy-based method, and each group is separately processed through the HAR algorithm in order to remove the artifacts while preserving the tumour response. The MAR algorithm allows inclusion of multistatic signals in the imaging in

* Corresponding author.
*E-mail address:* m.elahi1@nuigalway.ie (M.A. Elahi).

http://dx.doi.org/10.1016/j.bspc.2017.01.006
1746-8094/

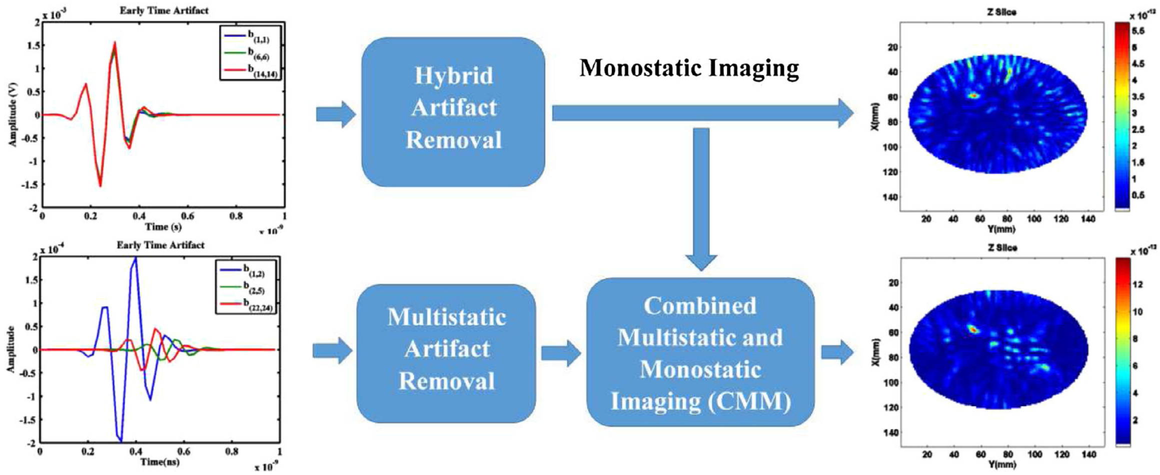


**Fig. 1.** Block diagram of the proposed method.

addition to the monostatic signals. The combined monostatic and multistatic (CMM) imaging approach improves the imaging quality compared to monostatic-only imaging approach. The block diagram of the proposed method is shown in Fig. 1. The algorithm is evaluated using anatomically and dielectrically accurate 3-D finite-difference time-domain (FDTD) breast models and a range of appropriate performance metrics.

The remainder of the paper is organized as follows: Section 2 describes extension of the hybrid algorithm to multistatic artifact removal; Section 3 describes experimental setup and 3D numerical breast phantoms; Section 4 details various tests applied to the artifact removal algorithm and corresponding results; finally, conclusions and suggestions for possible future work are discussed in Section 5.

## 2. Multistatic artifact removal

The general assumption about the multistatic signal acquisition approach is that an increased number of radar signals provide more information about strong scatterers present within the breast. However, the improvement in the multistatic images may not be incremental as each additional multistatic signal is added [5,6]. The selection of good quality multistatic signals for multistatic imaging can significantly improve the overall imaging provided the early-stage artifacts can be effectively removed.

The HAR algorithm has shown promising results when applied to monostatic signals due to the similarity of the monostatic artifact in all channels (Fig. 2(a)). However, it cannot be directly applied to the multistatic signals due to greater variation in the artifact (Fig. 2(b)). The channel to channel variation in artifact depends upon the propagation path of the signal between the transmitting and the receiving antennas, which makes it more challenging to estimate and remove the artifact. However, it is possible to identify and group the multistatic signals having similar artifacts so that the HAR algorithm can be separately applied to each group.

The performance of HAR is dependent on the degree of similarity between the signals in each group, which may vary across all signal groups. This is due to the fact that the Wiener filter estimates the artifact in a particular channel based on the artifact present in all other channels. If there is greater variation in the artifacts in the other channels, the estimated artifact will be less accurate. The greater variation in the artifacts also affects the artifact-dominant time-window estimation. Therefore it may not be possible to effectively remove the artifact from each signal group and it is important to adaptively select only those signal groups where the artifact can be effectively removed in order to achieve better quality images.

### 2.1. Signal grouping method

The signal grouping is based on the spacing between the transmitting and receiving antenna pair. The initial signal grouping is similar to the grouping described in [6]. Let $b_{(i,j)}$ be the backscattered signal recorded at antenna $j$, where $i$ is the index of the transmitting antenna, $j$ is the index of the receiving antenna, $i = 1, \ldots, N$, $j = 1, \ldots, N$ and $N$ is the total number of antennas in the array. The signals of the form $b_{(i,i)}$ are the monostatic signals with similar early-time artifacts, and therefore can be combined into one group. The early-time artifact is expected to be also similar for the signals of the form $b_{(i,i+k)}$ and $b_{(i+k,i)}$ where $i + k \leq N$ and $i$ is the index of the transmitting antenna, hence a total number of $L$ groups can be formed [6].

The similarity between signals in each group is dependent on the spacing between transmitting and the receiving antenna pair and the distance from the skin. For example, the transmitting-receiving antenna pair (1, 2) and (6, 7) have identical spacing and a common distance from the skin. Therefore the skin-artifact in the signals $b_{(1,2)}$ and $b_{(6,7)}$ is similar, as shown in Fig. 3(b). It can be seen that the degree of similarity between signals of the form $b_{(i,i+1)}$ is not identical but very similar to the monostatic signals whereas it decreases with increasing $k$, as shown in Fig. 3(c) (where $k = 2$) and Fig. 3(d) (where $k = 3$). This decrease in similarity can be attributed to increased spacing between the transmitting-receiving antenna pairs and the varying shape of the breast with increasing $k$. The decrease in similarity directly effects the performance of the HAR algorithm which is independently applied to each signal group.

### 2.2. Adaptive signal selection

The authors propose an entropy-based method to adaptively select the useful signal groups from a total of $L$ groups and signals within each group, in order to achieve better signal-to-clutter (S/C) ratio in the resultant multistatic images compared to a monostatic image formation approach. In the proposed algorithm, entropy is used to measure the degree of similarity between signals within each group, and compared with other groups in order to select useful multistatic signals. The similar artifacts in the early portion of the radar signals result in a larger value of entropy, whereas much