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Evaluation of Experimental Microwave Radar-Based Images: Evaluation Criteria

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Abstract—Microwave imaging has seen an increasing amount of clinical trials in the last two years, including ongoing and planned commercial development. The rapidly increasing number of studies with patient imaging is encouraging researchers to focus on the challenges of translating microwave imaging algorithms to clinical use. A large number of imaging algorithms have been proposed for radar-based imaging, however few detailed comparisons of these algorithms using realistic experimental or patient data have been published. This paper looks at two leading radar-based algorithms in experimental phantoms with and without tumours present. It shows that although some algorithms improve image quality when the tumour is present, the algorithms can also increase false positives in breast phantoms containing glandular structures.

I. Introduction

Many algorithms have been proposed for microwave imaging and these have been comprehensively reviewed in recent books and reviews [1], [2]. Although a number of studies have compared algorithms in idealised situations, few have considered performance using realistic artefact removal [3], [4]. No study to date has compared performance when using average dielectric properties estimation, which has been shown to have a positive impact on image quality [5], [6]. Additionally, few comparisons have included test scenarios both with and without tumours.

The goal of this paper is to highlight the importance of evaluating imaging algorithms on true positives and false positives in experimental breast phantoms. The ideal algorithm weights areas corresponding to tumours highly and does not reward cases where no tumours are present. Additionally, algorithms need to be robust to additional sources of noise due to clinical use, such as patient movement, patient breathing or inconsistent coupling between antennas and the breast [7]. In this work, two leading, imaging algorithms identified from a recent comparison [4] are analysed in a realistic experimental scenario.

II. Methods

Delay-and-Sum (DAS) [8] and Delay-Multiply-and-Sum (DMAS) [9] are used for image reconstruction. Recent evaluations have identified DMAS as effectively supressing background clutter in images containing tumours [4]. DMAS extends DAS by pair-wise multiplying each signal prior to summation which greatly increases the processing time [9]. For both algorithms, backscattered data was first processed using rotational subtraction [3], [6] to dampen the skin response and other artefacts. Signals were then synthetically focused to points within the imaging domain, where the average dielectric properties were estimated using a parameter search algorithm [6].

The experimental breast and tumour phantoms used in this paper are described in [6]. The imaging algorithms are assessed on images from a breast phantom with 15% glandular tissue by volume. Images reconstructed with 8 mm, 10 mm and 13 mm diameter tumours are analysed, as well as with no tumour present. The maximum amplitudes, signal-to-clutter (SCR) and signal-to-mean ratios (SMR) for the tumour and no tumour images are compared, defined as in [4].

III. Results

Images using DAS and DMAS are shown in fig. 1. Comparing the DMAS images to those reconstructed using DAS (figs. 1c and 1d to figs. 1a and 1b), it can be seen that although DMAS improves the quality of the image when the tumour is present, DMAS also improves the the quality of the images with no tumour present.

Quantatively, images from the three tumours and none are summarised in table I. For both DAS and DMAS, the tumour images have higher amplitudes compared to images with no tumour present. The SCR and SMR of images where tumours are present are also higher than without tumours present. In general, the SCR and SMR of DMAS images is higher than that of DAS images, as is the difference between the SCR and SMR of images with tumours compared to images without tumours present. However, for both SCR and SMR, DMAS improves the image without a tumour by a similar amount to images using from the 10 mm and 13 mm tumours respectively.

IV. Conclusions

Many algorithms have been proposed for microwave imaging, however few realistic comparisons using experimental or patient data are available. Additionally, experimental comparisons typically use cases where tumours are

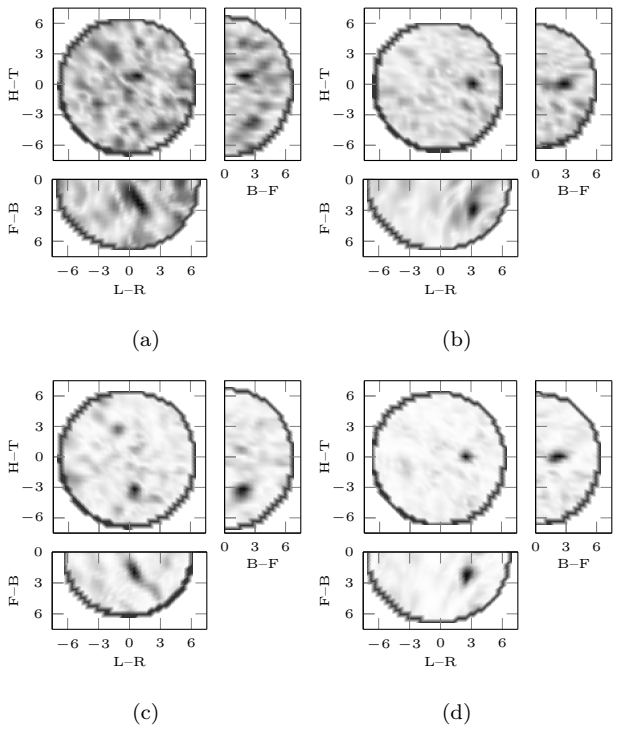

Fig. 1. Slices of maximum intensity with reference to the front (F), back (B), head (H), toe (T), left (L) and right (R) of the breast phantom. (a) and (b) are reconstructed with DAS, (c) and (d) are reconstructed with DMAS. (a) and (c) do not have a tumour present, (b) and (d) have a 10 mm tumour which is clearly identified by both algorithms. The breast phantom contains 15% glandular content by volume.

TABLE I
Quantitative evaluation of the images in dB for tumours of radius 0 mm, 8 mm, 10 mm and 13 mm. Although DMAS improves the quality of images in terms of SMR and SCR, DMAS images without tumours present show a similar improvement.

	DAS				DMAS			
	0	8	10	13	0	8	10	13
Max.	-35.8	-15.6	-12.6	-12.4	-85.4	-51.0	-45.6	-45.7
SCR	0.2	0.4	1.7	0.8	1.1	2.4	2.5	2.8
SMR	2	4	3.7	3.4	4.5	8.6	7.6	5.6

present, and do not consider the effect on images without tumours present.

In this work, the importance of considering images without tumours in experimental comparisons is indicated. Although DMAS reconstructs images with higher quality than DAS, this comes at considerable extra computational cost, and the potential effect on false positives is unknown. Furthermore, the largest radar-based clinical trial uses an image threshold of −1.7 dB for display to the clinician, meaning that increases in SCR above this threshold are not shown to the clinician for analysis and are not meaningful in that context.

As microwave imaging moves towards clinical use, detailed comparisons of microwave imaging algorithms in healthy breasts as well as breasts with abnormalities are required to determine the optimal algorithm for clinical efficacy. It is important to consider images with and without breast abnormalities, as well as the the image display methodology when comparing algorithms.

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