An Algorithm to Improve the Accuracy of Microwave Breast Imaging: Testing and Validation

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***Abstract*—Microwave imaging systems have become of increasing interest for their application to breast cancer treatment monitoring. These systems estimate and map the properties of tissues related to water content, namely permittivity. Though microwave imaging has shown promising results in initial clinical testing, more research is needed to investigate the effects of multipath propagation – a phenomenon where a signal takes more than one path from the transmitter to the receiver. Identifying multipath information allows information from all key paths through tissue to be incorporated into imaging algorithms. This paper presents the validation methodology for testing a signal processing algorithm that incorporates multipath information for a microwave transmission system. This algorithm was validated using both simulations and patient data. Additionally, the results from the multipath algorithm are compared to those when multipath information is not used. The results from this work indicate that incorporating multipath information enables the imaging system to better highlight regions of interest in permittivity maps. Therefore, during cancer treatment monitoring, this approach is expected to permit localization of treatment related changes, such as post-surgical fluid pockets (seroma) and regions with edema or inflammation.**

I. INTRODUCTION

High rates of breast cancer in North American women have prompted research into new methodologies for breast imaging to improve patient care [1]. Microwave imaging is a promising candidate as it is comfortable, non-ionizing and can be performed at point of care. However, due to the complexity of breast tissue, signals can travel both through and around inclusions like a tumor or seroma, resulting in multipath propagation. Ignoring the information from one or more of these paths results in less accurate permittivity estimates. Therefore, incorporating multipath information is expected to help microwave imaging systems more closely monitor changes in the breast during imaging.

A signal processing algorithm has previously been developed to incorporate multipath information into the permittivity estimates obtained with a microwave imaging system that uses signals transmitted through the tissues [2] [3]. This was accomplished by decomposing the signals transmitted through the breast into individual paths through tissue. However, this algorithm was only tested and validated with simple simulations. The work described in this paper aimed to validate the multipath algorithm in a complex environment with simulations of realistic breast models and then test the algorithm with patient data.

II. TESTING AND VALIDATION

Complex Breast Simulations:

The results from the system were initially analysed using simulated data. These simulations were performed using a finite difference time domain simulation software (SEMCAD, SPEAG, Switzerland). All complex simulations consisted of a slab (70mm high, 200mm wide and 90mm long) of fatty tissue (represented with a Debye model -- group 3 from [4]) surrounded by a 2.5mm layer of skin (relative permittivity 37 and conductivity 1.1 S/m). The glandular tissue was adapted from an anthropomorphic breast model repository [5]. Specifically, the glandular tissue of the breast models was resized (45mm high, 167mm wide and 83.7mm long) to fit inside the fat slab in the simulation. Six simulations were performed, all with a different distribution of glandular tissue. The simulated results were then processed with both the multipath and original algorithms. Nine additional simulations with a spherical inclusion (representing a tumor) placed inside the glandular tissue at various locations were also analyzed.

First, signals from each simulation were examined to determine whether multipath was present where expected. When examining the signals from antenna pairs imaging a region with only one type of tissue, only one peak was seen in the signal. However, when both fatty and glandular tissue were imaged by the antenna pair, multiple peaks were seen in the signals indicating multipath. Example signals can be seen in **Fig. 1.**.

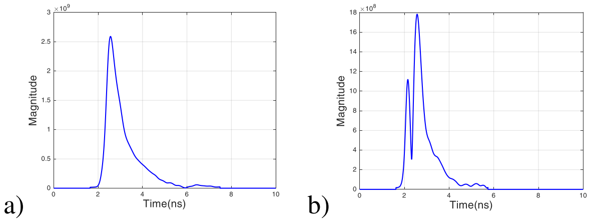

Fig. 1.: Example signal from a complex breast simulation traveling through a) fat and b) both fat and glandular tissue.

Next permittivity maps of each simulation were created with and without the multipath algorithm and then compared (**Fig.2.**).

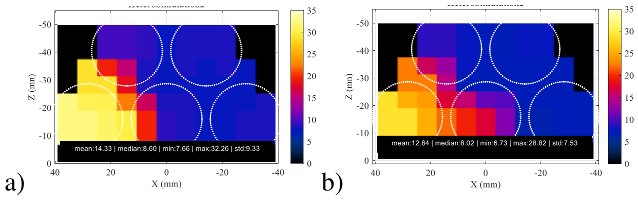

Fig. 2.: Permittivity map of complex breast simulation of heterogeneously dense breast processed a) without and b) with multipath information.

When analyzing the simulation results, the multipath algorithm produced similar results to the original processing algorithm in homogeneous regions, as expected. In a few areas where the simulation contained both dense and fatty tissue, the multipath algorithm was better able to outline the contour of the dense tissue. When a spherical inclusion was added to the simulations, the inclusion was more discernible from the background tissue when multipath information was included.

Patient Scans:

The multipath algorithm was also used to process data collected from breast cancer patient scans. These patients were recruited from the ACCEL clinical trial and provided informed consent [6] (Study approved by HREBA.CC-17-0322). Each patient was scanned by the Transmission System [3] up to four times over the course of their cancer treatment.

As with the simulations, the approximate locations of the inclusions (ie. glandular tissue and seroma) needed to be determined to aid in interpreting hotspots in the permittivity maps when using the multipath algorithm. Available mammograms and CT scans were therefore used as reference images for the microwave images to provide some insight into the composition of the tissue being imaged. To highlight the glandular tissue in the mammogram the open-source MATLAB breast segmentation algorithm – OpenBreast [7] was used. An example mammogram that has undergone image registration and segmentation is shown in **Fig. 1.**

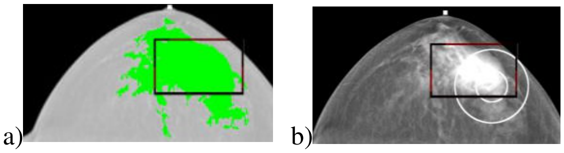

Fig. 2. Mammogram for a patient's treated breast. The black box indicates the location of the microwave image. a) Glandular tissue is highlighted in green. b) Approximate location of seroma and treated volume indicated by white circles.

In general, the regions highlighted by the multipath algorithm corresponded to the areas on the mammogram with dense tissue or an area where a response to cancer treatment should be visible. These areas were much more obvious when the multipath algorithm was used (**Fig. 3.**).

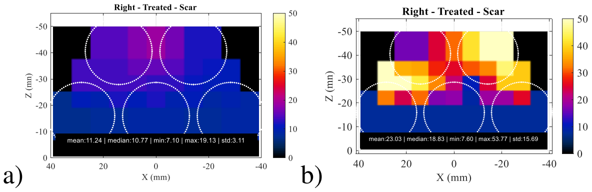

Fig. 4.: The permittivity maps for a patient's treated breast generated a) without and b) with the multipath algorithm.

Additionally, when the multipath algorithm was used to process the data from one patient over the course of cancer treatment, it was able to show changes in the permittivity maps over time as a response to cancer treatment in the treated breast.

III. CONCLUSION

A multipath signal processing algorithm was tested and validated using complex breast simulations and patient data. Complex breast simulations were used to demonstrate that the multipath algorithm produced accurate results in a complex environment and that multipath information was beneficial for locating inclusions within the tissue. Next the permittivity maps were created using breast cancer patient data and these maps were compared to sections of the patient's segmented mammogram. In this scenario, the multipath algorithm was useful in locating inclusions in breast tissue and tracking changes over time.

IV. ACKNOWLEDGEMENTS AND FUTURE WORK

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V. REFERENCES

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