Study of Practical Limitations of Real-Time Microwave Imaging of Tissue

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Microwave imaging finds applications in a variety of fields, e.g., remote sensing, underground surveillance, concealed weapon detection. Microwaves also hold a great potential in the imaging of tissue. However, microwave tissue imaging has not yet become commercially viable for use in clinical practice. There is a number of fundamental algorithmic and hardware challenges resulting from the complex propagation environment in tissue at the microwave frequencies. Here, we focus on some of the practical limitations of the real-time microwave imaging of tissue.

Early experiments have shown that the *spatial resolution* with microwaves is on the order of a centimeter. The spatial resolution limit is inherently related to the frequency range of the microwave radiation with the resolution improving at shorter wavelengths through the *diffraction limit*. Tissue imaging typically requires sub-centimeter resolution, which in turn implies the need to employ wavelengths shorter than 1 cm inside the tissue. However, there is a significant signal attenuation at such high frequencies. As a result, the *penetration depth* is severely limited. Therefore, beating the diffraction limit is of crucial importance. One way is to capture evanescent field information via near-zone measurements. Another way of overcoming the diffraction limit is to use nonlinear iterative reconstruction, which critically depends on the fidelity of the forward model.

Recent advances in the microwave imaging show that quantitative images require experimentally-acquired forward models [Amineh *et al*., 2015, Tu *et al*., 2015]. This requirement imposes additional challenges as it necessitates the availability of reliable system calibration methods. For example, quantitative microwave holography [Tajik *et al*., 2016] and scattered-power mapping [Shumakov *et al*., 2016] both exploit calibration measurements of an electrically-small scatterer embedded in the background medium. The dielectric properties of such a calibration object have to be close to those of the inspected object in order to achieve accurate quantitative results. However, tissues in the human body are known to be strongly heterogeneous electrically. Thus, the development of new calibration methods that do not dependent on *a priori* knowledge of the inspected object is necessary. Further, the electric field at the antenna location needs to be linked to the measured responses, e.g., the *S*-parameters [Beaverstone *et al*., 2016]. This is critically important to the fidelity of the data equation used in direct reconstruction as well as in nonlinear iterative reconstruction.

Novel calibration methods for improving tissue imaging are discussed. These build on recent work suggesting measurements of electrically small dielectric or metallic objects (scattering probes) that can produce the system-specific Green's function and the illuminating field. We investigate and compare the results produced by the dielectric and the metallic scattering probes. The impact of the shape of the probes and the electrical properties of the dielectric probes on the accuracy and the sensitivity of the system are investigated. The calibration method based on scattering-probe measurements is verified in tissue imaging where the inversion is performed using two direct methods: quantitative microwave holography and scattered-power mapping.