Microwave Imaging in Medicine: Promises and Future Challenges

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Abstract

Medical microwave imaging techniques seek to exploit dielectric-properties contrast mechanisms that are sensitive to physiological or pathological factors of clinical interest. The dawn of the 21st century has brought exciting prospects for innovative microwave sensing technologies to address diagnostic needs in medicine, particularly early-stage breast cancer detection. Yet numerous challenges need to be overcome in order to achieve the promise of microwave breast imaging in a clinical setting. This general lecture will highlight recent advances in the field of medical microwave imaging and strategies for moving forward towards clinical realization.

Summary

Medical microwave imaging has been the ultimate goal of numerous electromagnetic sensing explorations over the past several decades. The concept of using of non-ionizing microwave-frequency electromagnetic waves to image the human body – that is, to image the microwave dielectric properties or microwave scattering and absorption characteristics of tissue – has intrigued engineers and clinicians alike. The dielectric properties of human tissue are influenced by physiological factors of clinical interest, such as water content, temperature, and vascularization. Low-power microwaves can be used to sense and image these properties in a low-cost manner that poses no health risk to the patient.

A wide variety of potential medical applications of microwave imaging, ranging from pediatric transcranial brain imaging to the detection of ischemic heart disease, has been reported in the literature. The application that has experienced the most dramatic surge in interest over the past 10 years is breast cancer detection. For example, in the 1990's, there were approximately a dozen journal papers related to microwave breast imaging, whereas between 2000 and the present, over 100 journal papers have appeared, with over one third of those published in the past two years. The body of work on active microwave techniques for breast cancer detection is quite diverse, and includes narrowband and wideband inverse scattering techniques; ultrawideband beamforming and other impulse-based techniques such as time reversal; hybrid techniques such as microwave-induced thermo-acoustic tomography and microwave imaging with mechanical or acoustic excitation; and microwave holography.

Why has microwave imaging garnered such strong interest as an alternative non-ionizing breast imaging modality, and why has microwave imaging research been so focused on the specific problem of detecting early-stage breast cancer– a problem that has proven to be immensely challenging for existing clinical modalities, in terms of both sensitivity and specificity? In comparison to other areas of the human body, the breast is an accessible tissue volume that is outside any major muscle wall, making it a relatively low-loss environment for microwave sensing. Various dielectric contrast mechanisms are at play over much of the non-ionizing electromagnetic spectrum. The microwave frequency regime strikes a balance between the competing demands of penetration depth and imaging resolution. The anticipation of a large contrast between malignant and normal breast tissue, as suggested by early dielectric spectroscopy studies, has also been a significant motivation behind ongoing research. However, the landscape has been altered somewhat by a recent large-scale study of the dielectric properties of human breast tissue obtained from reduction and cancer surgeries, which revealed that the dielectric contrast is indeed significant in fatty breast tissue, but much smaller in fibroglandular tissue than previously thought.

In this general lecture, I will highlight the potential role of microwave imaging in breast cancer detection and monitoring of treatment as well as other biomedical imaging applications, review recent advances in microwave imaging algorithms and sensor systems, showcase laboratory and pre-clinical results obtained by leading research groups around the world, and identify challenges that need to be overcome and promising directions to be pursued in order to fulfill the potential of microwave imaging, particularly for breast cancer detection.