Mini-Symposium Title:

MICROWAVES IN BIOMEDICAL APPLICATIONS - PART III: Diagnostics and Therapy

Mini-Symposium Organizer Name & Affiliation:
Milica Popović, McGill University

Mini-Symposium Speaker Name & Affiliation 1:

Robin Augustine, Uppsala University, Sweden

Mini-Symposium Speaker Name & Affiliation 2:

Natalia NIkolova, McMaster University, Canada

Mini-Symposium Speaker Name & Affiliation 3:

Marko Helbig, Technische Universität Ilmenau, Germany

Mini-Symposium Speaker Name & Affiliation 4:

Susan Hagness, University of Wisconsin – Madison, USA

Theme:

- ○ 01. Biomedical Signal Processing
- ○ 02. Biomedical Imaging and Image Processing
- ○ 03. Micro/Nano-bioengineering; Cellular/Tissue Engineering &
- ○ 04. Computational Systems & Synthetic Biology; Multiscale modeling
- ○ 05. Cardiovascular and Respiratory Systems Engineering
- ○ 06. Neural and Rehabilitation Engineering
- ● 07. Biomedical Sensors and Wearable Systems
- ○ 08. Biorobotics and Biomechanics
- ○ 09. Therapeutic & Diagnostic Systems and Technologies
- ○ 10. Biomedical & Health Informatics
- ○ 11. Biomedical Engineering Education and Society
- ○ 12. Translational Engineering for Healthcare Innovation and Commercialization

Mini-Symposium Synopsis— Max 2000 Characters

Microwave imaging has gained interest in the past decades, due to demonstrated existing dielectric contrast between tissues at microwave frequencies, and motivated by the fact that such contrast would allow for modalities that complement currently used systems based on different underlying physics.

The contributions in this session report on a range of novel avenues in microwave imaging and therapeutic approaches. Phantom breast tissues have been a frequent subject of debate and challenge, due to the requirements to match the electrical and physical properties of breast, while remaining stable over time. The first paper addresses new findings on this topic. Second, near-field microwave holography is a fast microwave imaging method, however innovations are required for improved accuracy. A practical approach to obtaining the point-spread function that is demonstrated to provide enhanced accuracy when incorporated into the imaging algorithm. The third contribution explores pseudo noise sensing for the detection purposes. The final noted contribution reports on therapeutic approach of microwave ablation and consequently generated thermoacoustic signals.

The co-chairs for the session: Milica Popović (McGill University) and Elise Fear (University of Calgary).

Non-Invasive 2-Port Transmission Probe Based Tumor Detection Using Anthropomorphic Breast Phantom at 2.45GHz

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Abstract - In this paper, we propose the development of semi-solid and stable breast phantom with skin, fat, muscle and spherical tumor models and a transmission-based sensing method for tumor detection. The proposed breast phantom emulates the anatomical, physical and electrical properties as human breast tissues. The dielectric properties of the breast phantom tissues are measured using open ended coaxial slim probe from Keysight Technologies in the frequency range of 500 MHz-20GHz. The S21 scattering parameters are measured and studied for a normal breast phantom and breast phantom with tumor models representing its different growth stages using Topology Optimized Planar Antenna (TOPA) based probe. The study shows a detection an S21 amplitude variation of 2 - 12 dB for tumor inclusion models of size from 4mm - 16mm diameter with respect to normal breast model. This study indicates that with further development transmission-based methods can be used for preliminary screening of breast tumor.

Obtaining the 3D System Point-spread Function from a Single Calibration Measurement: Application to 3D Tissue Imaging with Near-Field Holography

Daniel Tajik and Natalia K. Nikolova, McMaster University

Abstract - Quantitative microwave holography reconstructs an object's 3D complex permittivity distribution within a couple of seconds even if the number of imaged voxels is on the order of a hundred thousand. Its accuracy, however, depends critically on the accuracy of the employed resolvent kernel of the inverse scattering model. Tissue imaging presents a near-field scattering scenario, the kernel of which is not amenable to analytical approximations or simulations. Instead, measured point-spread functions (PSFs) are employed in its derivation. The method requires a calibration PSF measurement with a scattering probe at each depth position where an image slice is desired. This makes the system calibration cumbersome if high-resolution 3D imaging is desired. We propose an analytical transformation which allows for obtaining the PSF at any desired depth from a single measurement with the scattering probe at the center of the imaged volume, the permittivity of which is that of the background medium. The accuracy of the transformation is confirmed in tissue-imaging experiments with simulated and measured data.

Magnetic Nanoparticle-Enhanced Microwave Breast Cancer Diagnostics

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Abstract – Magnetic nanoparticles (MNP) are of great interest for a variety of biomedical applications, e.g. as contrast agent for cancer detection, in which the MNP binds specifically to tumor cells. Therefore, the knowledge of the presence and the spatial distribution of the MNP inside of an organism is essential for a reliable detection of cancer cells.
There are different technologies, which exploit the magnetic properties of MNP to detect and image them, such as MRI [1], Magnetic Particle Imaging (MPI) [2] and Magnetorelaxometry (MRX) [3].
A further promising approach is the contrast enhanced microwave imaging [4, 5]. The detection of MNP based on a differential measurement. Supposing that an amount of functionalized MNP has accumulated in the tumor, its magnetic properties can be modulated by an external polarizing magnetic field (PMF). This results in a changing scattering behaviour, which can be detected by means of microwave sensing.
Fig. 1 shows the principal measurement setup. A transmitting antenna (Tx) emits a low power electromagnetic wave into the Material Under Test (MUT). The electromagnetic wave is reflected at each dielectric boundary and is recorded by the receiving antennas (Rx). If we change the magnetic field intensity H of the PMF, the scattering behavior of the MNP change, whereby the magnetic properties of the surrounding tissue are not affected due to their non-magnetic behavior. That implies that the undesired signal components (e.g. the antenna crosstalk) can be eliminated by subtracting two measurements with different states of the PMF, e.g. with and without the presence of the PMF.
In our presentation, we review our contrast enhanced microwave procedures by means of UWB M-sequence radar that enable the detection and the imaging of MNP in a biomedical environment.

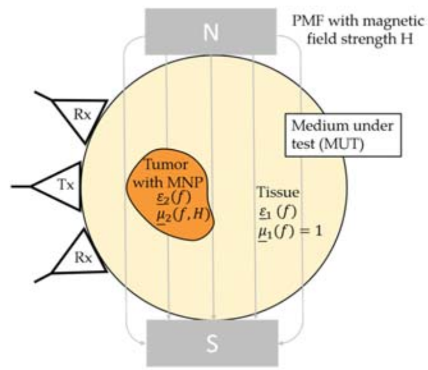

Figure 1. Generic MNP detection and imaging setup for biomedical applications.

The results of our *in-vitro* experiments showed that it is possible to detect MNP amounts of 1 mg of MNP in a volume of 2 mL [6]. Furthermore, we investigated the influence of the viscosity of the surrounding material in which the MNP are embedded.
Considering a practical measurement setup of breast cancer imaging, we are able to image a volume of 2 mL with a total amount of 10 mg MNP [5]. In order to improve the results, we investigated different parameters such as the optimal magnetic field strength and the influence of the kind of modulation of the PMF (i.e. ON/OFF or sine modulation) on the imaging results.

References

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[3] Wiekhorst et al., Pharm Res (2012) 29
[4] Bellizzi et al., IEEE Trans. on Biomed. Eng., vol. 58, no. 9, 2011
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Characteristics of thermoacoustic signals induced during pulsed microwave ablation

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***Abstract* –** Microwave ablation (MWA) is a minimally invasive thermal therapy in which an interstitial antenna delivers microwave power locally to diseased tissue to cause immediate necrosis. Low-cost, accurate, and non-ionizing imaging or sensing techniques for monitoring the spatial extent of the ablation zone are critical for effective MWA treatment. We are developing a new real-time MWA monitoring method using microwave-induced thermoacoustic (TA) imaging. This approach exploits the already present interstitial MWA antenna to simultaneously ablate and generate TA signals from within the treatment zone. TA signals generated by internally pulsed microwave energy is expected to increase the information content of the TA signals, eliminate the need for an external source for imaging, and dramatically reduce the cost, bulkiness, and complexity of existing MWA and imaging systems.

MWA is conventionally performed with a continuous wave (CW) source due to the convenience of commercially available CW microwave generators. The feasibility of performing MWA using a pulsed source – a prerequisite for generating TA signals – has been recently demonstrated. When pulsed microwave energy is absorbed by tissue, the tissue undergoes an incremental temperature rise which leads to thermoelastic expansion and the generation of an acoustic wave that can be detected by surface ultrasound transducers. The characteristics of the TA signals are linked to features of the local ablation environment from which they are generated, and thus can be exploited for ablation monitoring.

In this experimental and computational study, we examine the fundamental characteristics of TA signals generated from within the ablation zone and observe how the TA signal changes as the ablation zone evolves. We performed pulsed microwave heating experiments in non-coagulating and coagulating liquids using a single element transducer to measure the resulting TA signals. We also performed multiphysics simulations of the MWA process that encompass the electromagnetic, thermal, and acoustics physics. By comparing the simulations and experiments, we gain insights into acoustic signal generation and propagation during MWA.