Special Session Title:

MICROWAVES IN BIOMEDICAL APPLICATIONS - PART II:

Diverse Sensing Applications

Special Session Organizer Name & Affiliation:
Milica Popović, McGill University

Special Session Speaker Name & Affiliation 1:

Martin O'Halloran, National Univ. of Ireland, Galway

Special Session Speaker Name & Affiliation 2:

Susan Hagness, University of Wisconsin-Madison, USA

Special Session Speaker Name & Affiliation 3:

Paul Meaney, Dartmouth College, USA

Special Session Speaker Name & Affiliation 4:

Adam Santorelli, National Univ. of Ireland, Galway

Special Session Speaker Name & Affiliation 5:

Emily Porter, University of Texas at Austin, 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

Special Session 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. Microwave imaging and sensing methods have been proposed to fill clinical needs in scenarios where microwave frequency properties have the potential to provide diagnostically useful information. In this second part of the session, emerging biomedical applications of microwave imaging and sensing techniques are discussed. The papers in this session range from exploring new applications to improving imaging algorithms. Focusing on emerging applications provides an expanded perspective on this growing field, providing an important opportunity for the research community to discuss the potential for these technologies.

Microwave imaging has been proposed to investigate osteoporosis, and a 3D phantom to support these investigations is described. Techniques for monitoring microwave ablation are also explored. A point-of-care application of microwave technologies, specifically providing feedback on vertebrae strength during surgical procedures, is presented. New applications rely on an understanding of the dielectric properties of the tissues of interest. This final two papers in the session examine properties of blood clots and the relation to platelet content, as well as the role of histology in the interpretation of dielectric properties.

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

Microwave imaging system for osteoporosis diagnosis

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Abstract - Microwave imaging (MWI) has received significant attention as an emerging imaging modality for diagnosing various diseases. MWI exploits the dielectric contrast between healthy and diseased tissues of the target anatomical site. MWI has made significant progress towards breast cancer detection and for monitoring brain stroke. The clinical advantages of MWI are: portability, low cost and non-ionizing radiation that provides a safe alternative to existing imaging modalities for diagnostic and monitoring. Besides breast cancer detection and brain stroke monitoring, MWI has been recently proposed to measure in vivo dielectric properties of human calcaneus for monitoring osteoporosis. Osteoporosis is one of the major bone disease that mainly results due to demineralization of bones and hence results into bone fragility and fractures. Dual energy X-ray absorptiometry (DXA) scan is used as standard clinical modality for monitoring osteoporosis. But, DXA scan poses long term health risks as it employs standard X-ray doses. Therefore, a portable diagnostic device that does not use ionizing radiation is required for monitoring osteoporosis.

One of our *in vitro* study on human trabecular bone samples has shown that notable contrast exists between dielectric properties of healthy and osteoporotic bone samples, which are consistent with the difference in microarchitectural parameters (trabecular number, trabecular thickness and trabecular spacing) of healthy and osteoporotic bone samples. In order to exploit this notable dielectric contrast in the dielectric properties of human bones for the diagnosis of osteoporosis, a microwave tomography imaging system is being developed at the Translational Medical Device Lab, National University of Ireland Galway (NUIG). In this paper, a realistic multilayered 3D-printed human calcaneus phantom will be presented. This phantom has been developed for the evaluation of newly microwave tomography system at NUIG. Each layer of the phantom represents skin, muscle, cortical bone and trabecular bone. Each layer of the 3D-printed model will be filled with its corresonding liquid based tissue mimicking mixture (TMM). The proposed multilayered 3D-printed model and imaging prototype can be used for pre-clinical assessment of the microwave imaging system for oseteoporosis diagnosis.

Acknowledgement

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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 heating and cell death. Low-cost, non-ionizing, and accurate 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. The generation of TA signals via internally pulsed microwave energy is expected to increase the information content, 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 or 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.

Transmission-mode, coaxial probe for vertebrae quality testing during spine surgery

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Abstract - We have developed a coaxial, transmission-based probe for measuring bone quality during the instrumentation phase of spinal fusion surgery to assess whether the vertebrae are sufficiently strong to withstand the strain of the support screws. Failures of the screws can be catastrophic possibly leading to paralysis and even death. A major contributor to failure is osteoporosis in the bones. While surgeons routinely perform pre-surgical dual energy x-ray exams (DXA), the DXA images are notoriously variable and potentially misleading for vertebrae imaging. A point-of-care device would be more optimal in assessing overall strength and informing surgical decisions. The current probe design builds largely on new coaxial transmission-based probes which have the advantage of being able to measure tissue volumes as large as 2 cm thick. Unlike their single-ended, reflection-based probes, the new probes are not susceptible to large artifacts associated with even slight motion of the connecting cables. In addition, the vertebrae application is ideally configured for this concept because the surgical procedure involves opening up holes through the pedicle arms on both sides of the vertebrae. Early tests on ex vivo bone samples suggests the technique can distinguish between different bone densities.

Dielectric characterization of human blood clots to differentiate platelet-rich clots in ischaemic stroke

Abstract - Platelet-rich blood clots require a different intervention method during ischaemic stroke treatment from red blood cell rich clots. In this paper, an open-ended coaxial probe method is used to measure the dielectric properties of human blood clots formed with a range of platelet concentrations across the microwave frequency range. We investigate the correlation between the dielectric properties across this frequency range and the platelet content of the formed blood clots. Furthermore, we develop a model to predict the platelet level of an unknown blood clot based solely on the measured dielectric properties. This prediction may allow the characterization of unknown blood clots to be identified as platelet-rich or not, and thus inferring further clinical actions.

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National University of Ireland, Galway

Inadequacies of Histology for Interpreting Dielectric Measurements of Heterogeneous Tissues

Emily Porter, Department of Electrical and Computer Engineering, University of Texas at Austin, USA

Abstract – The dielectric properties of biological tissues are fundamental to the design, development, and clinical efficacy of medical microwave technologies. These properties characterize the interaction of electromagnetic fields with the human body, and describe the proportion of fields that are absorbed by, reflected by, and transmitted through the body. Typically, dielectric properties of tissues are measured using an open-ended coaxial probe. However, this method is designed for the measurement of homogeneous materials while tissues are often heterogeneous. In particular, breast tissues are highly heterogeneous and may be composed of adipose, glandular, and tumour tissue, along with blood vessels. As a result, the reported dielectric properties of such tissues have been highly variable. Histological analysis of tissue samples may be conducted to aid the dielectric characterization of heterogeneous samples. However, there are challenges with using histological analysis for this purpose which have gone unexamined in the literature to date. This work will discuss and quantify the errors introduced in the interpretation of the dielectric data, through each of the steps of the histological process. The results of this analysis indicate that errors in the histology process are causing errors in the interpretation of dielectric data of key tissues. Therefore, the dielectric properties that medical microwave technologies are based upon may have higher uncertainties than previously thought. Future work will be needed to develop more reliable methods for obtaining accurate dielectric measurements of highly heterogeneous tissues, in order to support clinical translation of microwave technologies.