

Mini-Symposia Title:

MICROWAVES IN BIOMEDICAL APPLICATIONS - PART II:

Diverse Sensing Applications

Mini-Symposia Organizer Name & Affiliation:

Milica Popović, McGill University

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Mini-Symposia Speaker Name & Affiliation 2:

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Mini-Symposia Speaker Name & Affiliation 3:

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Paul Meaney, Dartmouth College, USA

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Bilal Amin, National Univ. of Ireland, Galway

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-Symposia 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.

Examination lymph nodes in the axilla is proposed to aid in breast cancer staging, and detailed anatomical models are developed to support feasibility analysis. Microwave imaging has been proposed to investigate osteoporosis, and a 3D phantom to support these investigations is described. 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).

Axillary Region Numerical Models for a Microwave Imaging System

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Abstract - Breast cancer accounted approximately 2.09 million new cancer cases in 2018, being the second most common cancer worldwide and the most common among women. The tumour can drain cancer cells to surrounding lymph nodes, such as axillary lymph nodes (ALN), in most breast cancer cases in stages II to IV.

We aim to design and build a full Microwave Imaging (MWI) system to detect and diagnose ALNs. MWI has been used for early detection of breast cancer, but the evaluation of ALNs has only been addressed in a few publications. Our system will be based on Ultra-Wideband (UWB) radar microwave imaging, which consists in illuminating the axilla with a UWB pulse and recording the backscattered signals by one or more antennas. Those signals will be used to create an energy profile of the axilla. The focus of this paper lies on the creation of an axillary region model which is required to test and validate this MWI system.

In this paper, we analyse two different sequences of MRI images of the upper torso, 3D T1-weighted and DIXON, both with a voxel-size of 1mm x 1mm x 1mm acquired with a dedicated coil for the breast to build an anatomically-realistic model of the axillary region. The images were pre-processed and segmented in four main steps. Firstly, pre-processing filters were applied to the images in order to remove artifacts, while preserving the edges and increasing the signal-to-noise ratio. Then, we segmented the images into two tissues, the background and the torso, using manual thresholding and some manual corrections. The torso itself was then segmented using the K-means clustering algorithm which is an unsupervised method that, when applied to images, divides the data into K groups based on their voxel intensity values and location. The images were segmented into an optimal number of tissues which can be labelled as lymph nodes, different categories of fibroglandular tissue and fat, and other anatomical structures. In the last step of segmentation, we applied a skin detection algorithm and merged the segmented skin with the previous segmented data. Finally, we assigned dielectric properties to each tissue by mapping the voxel intensities to several dielectric properties curves defined by. The permittivity and conductivity values of ALNs were interpolated from the

dielectric properties curves of fibroglandular tissue considering the voxel intensities values of each type of tissue.

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

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Abstract – Platelet-rich blood clots require a different intervention method from red blood cell rich clots during ischaemic stroke treatment. Currently, there is no easy way to identify the type of clot. If the type of blood clot can be identified during stroke treatment, the exact clot removal process can be chosen and patient outcomes can be improved. Previous work by our group has shown that changes in blood composition can be directly correlated to changes in the dielectric profile of a blood sample. These past results lead to the promising possibility of using the dielectric profile of a blood-clot to characterize whether it is platelet-rich or red blood cell rich.

In this work we aim to address two primary research questions: (i) can realistic blood-clots of varying platelet concentrations be formed?, and, (ii) can we use the dielectric profile of these blood clots to identify whether they are red blood cell or platelet rich blood clots. To characterize the dielectric properties of these formed clots an open-ended coaxial probe method is used to measure the dielectric properties across a wide frequency range. After the dielectric measurements are completed, histology on each blood clot is performed to determine the concentration of red blood cells present. In total, 14 unique blood clots were formed. Each unique blood clot was broken into two or three segments, depending on the total length. In total, 32 blood clot samples were measured (in some cases the formed blood clots were too thin to be used with the Keysight Slim Form Probe), and 32 histological analysis were performed, leading to 32 samples with unique red blood cell concentration.

With this completed analysis, we investigate the correlation between the dielectric properties across this frequency range and the red blood cell count of the formed blood clots. This analysis

was conducted at specific frequency points across the microwave range that correspond to approved ISM bands. Furthermore, we develop a model to predict whether an unknown blood clot can be categorized as red blood cell rich or platelet rich based solely on the measured dielectric properties. This prediction may allow clinicians to more easily determine treatment methods during an intervention.

Inadequacies of Histology for Interpreting Dielectric Measurements of Heterogeneous Tissues

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and Alessandra La Gioia, National University of Ireland Galway

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 under-examined in the literature to date.

This talk will discuss 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 studies 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.

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. This is partially because there is ample soft tissue in the intervening space above the spine during the x-ray imaging where the presence of normal and sometimes even calcified tissue may be present to skew the measurements. In addition, it is well known that there can be considerable density variation between adjacent vertebrae which can further confound the radiologists assessment. A point-of-care device would be more optimal in assessing overall strength and informing surgical decisions.

The current probe design builds largely on a 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.

For our initial experiments, we have tested bovine femur samples acquire from a local abattoir. In these cases, the animals were all roughly 6 months old. It is quite clear that the

bone densities on either sides of the epiphyseal plate near the end of the long bone are quite different. Those on the distal part are more cartilaginous with large amounts of fat interspersed while the proximal side is generally denser with more red marrow present. In these cases, the probes were held in a custom fixture with the starting point being roughly 1 cm deep from either side. Care was taken to aim the probes as directly at each other as possible. A transmission measurement was taken, after which the probes were removed and one side was drilled 2.5 mm deeper. The measurements were repeated and an additional 2.5 mm deeper hole was drilled on the opposite side. This procedure was repeated until the probes contacted each other. The techniques was used on both the proximal and distal parts of the bone, and a total of 17 measurement sets were collected.

The measurements were taken to assess the variability of the measurements as a function of probe separation distance. While the ultimate clinical probe will only be performed at a single position in the tissue so that magnitude and phase slopes can be computed for deriving the associated dielectric properties, we have chosen to perform more measurements on these samples for several reasons including the fact that because the animals have been sacrificed larger data samples can be gathered to assess the reliability and precision of the approach. This additional data acquisition allowed us to assess the omni-present multipath signals and how there interference could be mitigated. The initial experiments also provided valuable feedback in terms of other challenges we would encounter. The early results are encouraging in that they provided property values within our expected ranges given published literature. In addition, we can clearly distinguish the bone types for these two regions. These tests have proved very useful and set the stage for more comprehensive tests on human bone samples comparing both normal and osteoporotic bones.

Multilayered human calcaneus phantom for microwave imaging of bone

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Abstract—Microwave imaging (MWI) can be used as an alternate modality for monitoring bone health. Realistic phantoms play a vital role towards development of a clinical MWI system. This paper presents a realistic multilayered 3D-printed human calcaneus phantom for evaluation of MWI prototype. Each layer of the phantom was filled with respective tissue mimicking mixture (TMM). The considered layers of human calcaneus are: skin, cortical bone and trabecular bone. A measurement chamber having nine microstrip antennas was designed to hold human calcaneus phantom. The shape of the measurement chamber was similar to that of human calcaneus. This multilayered 3D-printed human calcaneus phantom can be used as a valuable platform for pre-clinical assessment of calcaneus for bone imaging applications.

Index Terms—microwave imaging, human calcaneus, tissue mimicking mixture, bone health.

INTRODUCTION

MWI is an emerging imaging modality for diagnosing and monitoring of various diseases such as breast cancer and brain stroke. The key clinical advantages of MWI over the already existing imaging modalities are portability, low cost and non-ionizing radiations [1]. Recent studies have shown that MWI can be used to monitor osteoporosis [2]. 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 widely used as standard clinical modality for monitoring osteoporosis. But, DXA scan poses long term health risks as it employs standard X-ray doses [2]. Therefore, a portable diagnostic device that does not use ionizing radiations is required for monitoring of osteoporosis. To the best of authors' knowledge, no dedicated anatomical model exists for bone imaging application.

METHODS

The 3D-modelling software Autodesk Fusion was used to produce a multilayered model of the human calcaneus. The shape of the calcaneus model was produced by using a 3D digital model of the human foot which was taken from an online 3D-modelling database. This digital foot model was used to produce an imprint of the calcaneus. The model was then divided into three separate chambers which would contain our liquid TMMs for skin, cortical bone and trabecular bone. To design a measurement chamber for human calcaneus, the imprint of the calcaneus model was modified in Autodesk Fusion and nine holes were created to place flexible microstrip antennas in direct contact with the human calcaneus

model. These models were then printed at 200°C using a PLA filament. The thickness of walls was kept 2mm to prevent leakage of liquid based TMMs and to avoid potential low field perturbation [3]. In this study our imaging anatomical site was calcaneus due to the fact that, the ratio of cortical to trabecular bone is similar to that found in the femoral head and lumbar spine which are considered as main scanning sites for osteoporosis monitoring [4].

RESULTS AND DISCUSSION

Each layer of the calcaneus model as shown in Fig. 1(a) was filled with respective TMM. The three layers of the calcaneus model were filled with skin, cortical bone and trabecular bone's TMM respectively. The combined average percentage difference between dielectric properties of reference data and proposed tissue phantoms was found to be 2.9% for trabecular bone, 7.3% for cortical bone, and 8.7% for skin over measured frequency band (0.5 – 8.5 GHz). In order to avoid the problems of leakage, trapped air, and weakness of the structure the thickness of the walls were kept to be 2mm. The proposed calcaneus phantom can be placed in measurement chamber shown in Fig. 1(b) to perform microwave measurements using a MWI prototype.



Figure 1 (a) The multilayered calcaneus phantom (b) The imaging prototype

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