Mini-Symposia Title:

MICROWAVES IN BIOMEDICAL APPLICATIONS - PART I:

Breast cancer detection and monitoring

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

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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 considerable interest, due to demonstrated existing dielectric contrast between tissues at microwave frequencies. Such contrast may allow for modalities that complement currently used systems based on different underlying physics. Many microwave-based systems are low-cost, making them accessible to small clinics and societies disadvantaged by challenging economic standards.
Research efforts in this field persist as they promise development of devices which could complement currently used modalities. Groups investigating this topic worldwide vary in their approach, but all rely on the reported inherent dielectric contrast between healthy and malignant tissues in the microwave frequency range. Different tissues have different water content and hence different microwave frequency properties. These properties are also anticipated to change with the health of the tissues.
The first part of the session will focus on application of microwave imaging to breast health, ranging from early detection to post-surgery tracking and treatment monitoring. A number of teams strive to address different challenges, such as sensor design, effective measurement techniques and hardware, noise level reduction, optimal signal processing and algorithm development and the overall system design. In this session, papers explore the development of phantoms used in testing and evaluation of systems and approaches to imaging. Several different approaches to imaging are also tested on both phantoms and human subjects. This testing is aimed at studying tumor detection in different challenging scenarios, as well as post-treatment changes.
The co-chairs for the session: Milica Popović (McGill University) and Elise Fear (University of Calgary).

The Viability of Carbon Fiber-doped 3D-printed Material as a Skin Surrogate in Breast Microwave Imaging

Stephen Pistorius, University of Manitoba, Canada

Abstract **–** Microwave imaging has emerged as a potential modality for breast cancer detection. As breast microwave imaging (BMI) systems move toward clinical use, rigorous preclinical evaluation using breast phantoms is required. MRI-derived 3D-printed phantoms are morphologically anthropomorphic but require the use of a 3D-printing material, resulting in plastic layers in the phantoms. These plastic layers may have undesirable features due to their low-permittivity, relative to the permittivity of breast tissues. In addition, the long-term reliability of skin-mimicking materials requires improvement.

This work used reflectivity and transmission measurements of 1-8 GHz microwave signals to explore the viability of using carbon fiber (CF)-doped plastic as both the outer layer of a 3D-printed phantom that contains the adipose tissue surrogate, and as a skin surrogate. The effects of material thickness and the polarization of the individual carbon fibers on the reflectivity of 3D-printed CF-doped plastic structures were examined. Comparisons to common low-permittivity 3D-printing plastics, including polycarbonate and polylactic acid (PLA), and other skin-surrogate material will be made. Preliminary results have demonstrated that the 3D print design will play an important role in optimising the magnitude of the skin-layer reflectivity and that the higher reflectivity of CF-doped plastics, 3D-printed shells produced with these materials may be suitable as a skin surrogate in BMI.

Development and Testing of Ultrasound and Microwave Tissue Phantoms for Breast Imaging Applications

Hannah Fogel, Pedram Mojabi and Joe LoVetri, University of Manitoba, Canada

Abstract - Development of breast phantoms for ultrasound and microwave imaging are considered in this paper. We also investigate the creation of dual-mode phantoms having both ultrasonic and electromagnetic properties of breast tissues. Having these phantoms is crucial as the first step for experimentally investigating the use of ultrasound prior information for microwave imaging using a hybrid ultrasound-microwave imaging system. Incorporating structural information obtained by ultrasound has previously been shown to enhance the reconstruction of electromagnetic properties [Abdollahi *et al.*, IEEE JMMCT, 2019].

The ultrasound phantoms are prepared using a recipe based on that of [Medina-Valdez *et al.*, Physics Procedia, 2015], using gelatin, glycerin and agar dissolved in water. Various tissue types can be mimicked by tuning the proportions of the different ingredients. For the microwave phantoms, two concentric 3-D printed plastic shells are filled with liquids having the desired electromagnetic properties, as described in [Asefi *et al.*, IEEE TMTT, 2019]. 3-D printed or blown-glass spheres are suspended as tumors inside the inner shell. Phantoms having both ultrasonic and electromagnetic properties similar to those of breast tissue are also being investigated.

The ultrasonic and/or electromagnetic properties of the phantoms are measured experimentally. The ultrasonic properties (sound speed and ultrasound attenuation) are calculated using the in-house ultrasound system at the University of Manitoba based on the method explained in [Mojabi *et al.*, IEEE JMMCT, 2019]. Electromagnetic properties of the phantoms (complex permittivity) are measured using a dielectric measurement probe.

Detectability of Breast Tumors in Excised Breast Tissues by A Portable Breast Tumor Screening Device

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***Abstract* –**The detectability of breast tumors in excised breast tissues of total mastectomy was investigated by the use of a portable impulse-radio-ultra-wide-band (IR-UWB) radar-based breast cancer detector. The confocal images of the breast tumors having various histological types were investigated in comparison with both histopathological microscope images and images of dedicated breast positron emission tomography.

The IR-UWB-radar-based detector consists of a 65 nm technology complementary metal oxide semiconductor integrated circuits (CMOS-IC) and a field programmable gate array (FPGA). The CMOS-IC in a transmitter-module generates Gaussian monocycle pulse (GMP) with pulse width of 160 ps. The center frequency and bandwidth of the pulse are 6 GHz and 3.1–10.6 GHz, respectively. The GMP is generated as a pulse train with the repetition period of 10 ns. Planar slot ultra-wide-band (UWB) antennas with the size of 11 mm × 13.1 mm × 0.635 mm were fabricated on a concave board to form a rotating antenna array. The surface of the antenna array is covered with a concave-shape housing which touches directly on a human breast. Received analog waveforms are converted to digital signals with 100 G Sample/s by equivalent time sampling.

Comparative study of confocal imaging was conducted for invasive and non-invasive cancers. Ductal carcinoma in situ (DCIS), which is non-invasive cancer and one of the early-stage lesions, could be detected as a bright spot as well as invasive ductal carcinoma (IDC). The important finding was that the IR-UWB-radar-based breast tumor screening device could detect multiple tumors in a dense breast, whereas X-ray mammography could not. The images of IDC mucinous primary tumor (PT) and extensive intra-ductal component (EIC) were reconstructed by the 3-D confocal imaging, which were also confirmed by a dedicated breast positron emission tomography (DbPET). Furthermore, two spots of IDC mucinous and IDC scirrhous carcinomas were reconstructed in the 3-D confocal image, which were also confirmed by DbPET.

According to the effective medium approximation theory, the effective permittivity of the breast tissue changes from 4 to 10, depending on the volume fraction of glandular tissues in the fatty breast. The typical dielectric constants of skin, fat, glandular and tumor tissues were approximately 36, 4, 34, 60, respectively, at 6 GHz. Therefore, the estimated value of the effective permittivity of the dense breast by confocal imaging must be greater than that of the scattered breast. In addition, the depth of the target spot in the reconstructed confocal image decreases when the effective permittivity of the confocal image increases.

In conclusion, the detectability of breast tumors in the excised breast tissues of total mastectomy was demonstrated by the use of the portable IR-UWB-radar-based breast tumor screening device with the confocal imaging algorism. It is found that the screening device could detect multiple tumors in the dense breast. The confocal image of DCIS can be reconstructed as a bright spot as well as IDC. The results of confocal images were consistent with the DbPET images and pathological diagnoses in terms of the occurrence site of breast cancer. The density of the breast had a correlation to the effective permittivity derived from the reconstructed confocal images. These results show that the portable IR-UWB radar-based screening device has a potential for screening early-stage breast tumors in terms of the occurrence site of breast cancer without ionizing radiation or pain.

Microwave imaging for breast treatment monitoring: initial results of scanning patients pre- and post-radiotherapy

Katrin Smith[1], Jeremie Bourqui[2], Petra Grendarova[3], Mark Lesiuk[3], Sarah Quirk[4], Michael Roumeliotis[4], Wendy Smith[4], James Pinilla[3] and Elise Fear[2]

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Abstract - Microwave imaging has been proposed to detect tumours in breast tissues, as well as track changes during treatment. Our team has developed a low-resolution imaging system that measures microwave signals transmitted through the breast. The travel time of these signals is used to estimate the average permittivity in the sensing volume, and these estimates are mapped to form low resolution images. Scans of healthy volunteers have previously been reported and results indicate that properties relate to the breast composition, as well as excellent consistency of scans over time.

To test the ability of microwave imaging to track changes in tissues with treatment, a pilot study has been initiated. This study has been approved by the Health Research Ethics Board of Alberta (HREBA.CC-17-0322). Patients are scanned after lumptecomy and prior to starting radiation treatment. A second scan is performed at an appointment 6 weeks after treatment is finished. Both the treated and untreated breasts are scanned. Comparison of the treated and untreated breasts at a single time point gives insight into the treatment responses tracked by the microwave imaging technique. Comparing scans collected at different time points provides insight into changes over time in the treated breast.

Microwave Radar Breast Tissue Screening: Verification of Prototype Function for Post-Biopsy Conditions with Titanium Clip Marker

Lena Kranold and Milica Popović

Electrical and Computer Engineering Department, McGill University, Montreal, Canada

Abstract – Within the research efforts on feasibility of microwave breast cancer detection, our group's work focuses on the time-domain radar approach. Here, the low-power microwave pulses emitted into the breast from the skin surface propagate and scatter within the complex breast tissue and the resulting detected signals are processed to reveal the location of the main scatterers within the breast volume. Our approach is aimed for tracking breast health frequently, over extended periods of time, so that the development of an anomaly can be detected through algorithmic comparisons of prior scans.

In this paper, we report experimental setup and measurements with breast tissue phantoms, ranging from the ones mimicking a healthy breast to those with a titanium clip embedded in a gland, in order to simulate the scenario of a patient who has undergone a biopsy and is left with the location-marking clip within the tissue. Our experiments indicate that the presence of this clip will still allow detection of a malign tumor which may develop after the biopsy.