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Session 3pBAb

Biomedical Acoustics, Signal Processing in Acoustics and Physical Acoustics: Interaction of Light and Ultrasound II

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Invited Papers

1:20

3pBAb1. Antivascular photo-mediated ultrasound therapy and its application in the eye. Xinmai Yang (Mech. Eng., Univ. of Kansas, 1530 West 15th St., Leaned Hall 3138, Lawrence, KS 66045, xmyang@ku.edu), Yannis M. Paulus (Dept. of Ophthalmology and Dept. of Biomedical Eng., Univ. of Michigan, Ann Arbor, MI), and Xueding Wang (Dept. of Biomedical Eng. and Dept. of Radiology, Univ. of Michigan, Ann Arbor, MI)

Antivascular therapy can improve the prognosis of a variety of pathological conditions, including cancer and many eye diseases. By synergistically applying laser pulses and ultrasound bursts, we developed a photo-mediated ultrasound therapy (PUT) technique as a localized antivascular method. PUT takes advantage of the high native optical contrast among biological tissues and has the unique capability to self-target microvessels without damaging surrounding tissue. The technique utilizes an integrated therapeutic ultrasound and laser system. The laser system emits 5-ns, 10-Hz pulses, which is synchronized with 10-ms, 10-Hz ultrasound bursts. Experiments were carried out on chicken yolk sac membrane and rabbit eyes. With radiant exposures around 5 mJ/cm^2at 532 nm and ultrasound pressures around 0.4 MPa at 1 MHz or 0.5 MHz, microvessels were able to be removed. Furthermore, *ex vivo* tests with human blood demonstrated that cavitation was induced when laser and ultrasound were utilized synergistically. On the rabbit eye model, the blood flow in microvessels could be greatly reduced after PUT, and the occlusion of microvessels could last up to 4 weeks. In conclusion, PUT holds significant promises as a non-invasive method to precisely remove microvessels in neurovascular eye diseases by more selectively treating vasculature with minimized side-effects.

1:40

3pBAb2. Optical mean irradiance change for inference of focused-ultrasound-induced strain and thermal expansion in tissue-like materials. R. Glynn Holt (Mech. Eng., Boston Univ., 110 Cummington Mall, Boston, MA 02215, rgholt@bu.edu), Ali Vakili, Joseph L Hollmann, and Charles A. DiMarzio (Comput. and Elec. Eng., Northeastern Univ., Boston, MA)

Inferring material properties in scattering media, especially tissue, is a commonly applied method for detecting flaws or abnormalities. Hybrid acoustic/optic methods are often employed to overcome the limitations inherent in one or the other. Such hybrid methods have achieved great success in imaging various features (mechanical or optical properties) at a variety of spatial scales down to the subcellular. Here, we seek to develop an intermediate resolution method of detecting changes in material properties that is robust, inexpensive, and potentially capable of real-time analysis. We exploit the ability of the time-averaged absorption of focused ultrasound to induce changes in the optical index of scattering materials. By combining simulations with experiments, we demonstrate that the optical mean irradiance change measurement is capable of revealing time-dependent index changes. We are able to separate the contributions of both thermal expansion and radiation force deformation in the correlation signal. Potential applications of this technique will be discussed.

2:00

3pBAb3. Combining light and sound with nanoparticles to identify and treat head and neck cancers. Teklu Egnuni (Leeds Inst. of Medical Res., St. James' Univ. Hospital, Leeds, United Kingdom), Li Chunqi (School of Electron. and Elec. Eng., Univ. of Leeds, Leeds, United Kingdom), Nicola Ingram, Louise Coletta (Leeds Inst. of Medical Res., St. James' Univ. Hospital, Leeds, United Kingdom), Steven Freear, and James R. McLaughlan (School of Electron. and Elec. Eng., Univ. of Leeds, University of Leeds, Leeds LS2 9JT, United Kingdom, J.R.McLaughlan@leeds.ac.uk)

High intensity focused ultrasound (HIFU) is a non-invasive and non-ionising approach used primarily for the thermal ablation of cancerous tumours. Even though it has been in clinical use for over 30 years, it has yet to achieve widespread use. Two key limitations for this approach are long treatment times and a difficulty in getting real-time feedback on treatment efficacy. One technique that could help with these limitations is a combination of HIFU, pulse laser illumination, and cancer targeted nanoparticles. When nanoparticles are simultaneously exposed to these modalities, vapour bubbles form, providing a controllable way to nucleate cavitation in the target location. Acoustic emissions from inertial cavitation can be monitored via passive cavitation detection and/or mapping. This approach provides direct localisation of cancerous regions and has greater sensitivity compared with current photoacoustic imaging. Once the

cancerous regions have been localised, they can be ablated by HIFU, which is known to be enhanced in the presence of cavitation, by enhancing thermal damage in a localised region. Furthermore, the acoustic emissions generated during these ablations could give an indication of treatment progress. This study will present data on both *in vitro* and *in vivo* validation of this approach in models of head and neck cancer.

Contributed Papers

2:20

3pBAb4. HIFU tissue lesion quantification by optical coherence tomography. Jason L. Raymond (Dept. of Eng. Sci., Univ. of Oxford, 17 Parks Rd., Oxford OX1 3PJ, United Kingdom, jason.raymond@eng.ox.ac.uk), E. Carr Everbach (Eng., Swarthmore College, Swarthmore, PA), Ronald Roy (Dept. of Eng. Sci., Univ. of Oxford, Oxford, United Kingdom), Manuel Marques, Michael Hughes, and Adrian Podoleanu (School of Physical Sci., Univ. of Kent, Canterbury, Kent, United Kingdom)

Heating of tissue by high-intensity focused ultrasound (HIFU) can result in sufficient temperature elevation to cause irreversible changes in the tissue structure. The contiguous volume occupied by these changes, a lesion, and the extent of the tissue changes may be quantified histologically or estimated through techniques such as ultrasonic elastography. We have shown that changes in tissue optical scattering could be used as a proxy to improve sensing and imaging of HIFU lesion formation as an alternative to thermometry. Optical coherence tomography (OCT) is a light-based method appropriate for optically accessible tissues, which we have used to quantify lesion volume, shape, and quality based upon the irreversible changes in optical scattering that occurs with protein denaturation. We have adapted OCT to take into account changes in optical polarization of the tissue, providing sensitivity to changes in the collagen orientation of skin with heating. This technique has potential in detecting antecedents of skin burn during HIFU exposures, thereby increasing safety and reducing treatment times.

2:35

3pBAb5. Evaluation of a potential medical diagnosis application of sonoluminescence. Alicia Casacchia (Walker Dept. Mech. Eng., Univ. of Texas at Austin, 204 E. Dean Keeton St., Austin, TX 78712, acasacchia@utexas.edu), Parker George (Plan II Honors Program, Univ. of Texas at Austin, Austin, TX), Preston S. Wilson, and Mark F. Hamilton (Walker Dept. Mech. Eng., Univ. of Texas at Austin, Austin, TX)

Sonoluminescence (SL) is a phenomenon in which light is produced via violent collapse of a gas-filled cavity under excitation by a varying pressure field. Although the precise mechanism of this light production is not yet agreed upon in the literature, various applications of this effect have been established and are continually being developed. One such example of an application of this phenomenon that has not been extensively studied is the production of SL in biological fluids as a method for medical diagnostics. Measurements performed by Chernov *et al*. [in Proceedings of 14th International Symposium on Nonlinear Acoustics (1996), pp. 219–223] revealed varied intensities of SL emissions in blood plasma samples from groups of patients diagnosed with different diseases. We present an experimental apparatus for the production of single bubble sonoluminescence (SBSL) and subsequent measurement of radial oscillations using optical scattering techniques. This system will allow for characterization of the effects of both the biological fluid content and viscoelasticity on the spectra of SBSL light emissions. Additionally, these experimental results can be used to inform future computational models of this behavior. [This is a Plan II SAWIAGOS project.]

2:50

3pBAb6. Deep-learning framework and acoustic reflector for improved limited-view and sparse photoacoustic tomography. Irvane Ngnie Kamga, Steven Guan, and Parag V. Chitnis (BioEng., George Mason Univ., 12300 Oak CreenREEK Ln., Apt. 1009, Fairfax, VA 22033, ingnieka@gmu.edu)

Photoacoustic imaging is a hybrid imaging modality that relies upon optical absorption of pulsed light and subsequent thermoelastic generation of ultrasound. The detection of the induced acoustic waves outside the tissue enables image reconstruction. A major challenge encountered in photoacoustic tomography (PAT) lies in the inability to acquire complete projection data from the region of interest due to both the limited view and sparsity of available ultrasonic sensors. The resulting images are characterized by severe artifacts and poor quality. In this work, we examined the utility of incorporating an acoustic reflector to address the limited view problem and to train a convolutional neural network (CNN) to improve PAT image reconstruction from sparsely sampled data. Photoacoustic wave propagation was simulated in MATLAB using the k-Wave toolbox. We compared the performance of a sparse linear transducer array (with and without reflector) to that of a circular transducer array. The structural similarity index (SSI) was used as a metric for evaluating image quality. The combination of a curved reflector and artifact-removal using a CNN improved the quality of PAT images from the linear configuration. The resulting mean SSI value (0.859) was comparable to that achieved using the circular transducer array (0.926).

3:05

3pBAb7. Pixel-wise deep learning for improving image reconstruction in photoacoustic tomography. Steven Guan, Amir Khan, Siddartha Sikdar, and Parag V. Chitnis (BioEng., George Mason Univ., 4400 University Dr., Fairfax, VA 22030, Sguan2@gmu.edu)

Photoacoustic tomography involves absorption of pulsed light and subsequent generation of ultrasound, which when detected using an array of sensors can produce clinically useful images. Practical considerations limit the number of sensors and their "view" of the region of interest (ROI), which can result in significant reconstruction artifacts. Iterative-reconstruction methods can improve image quality but are computationally expensive. Another approach to improve reconstructed images is to use convolution neural networks (CNN) as a post-processing step for removing artifacts. However, missing or heavily obscured features typically cannot be recovered using this approach. We present a new pixel-wise deep learning (PDL) approach that employs pixel-wise interpolation to window ROI-specific raw photoacoustic data and then directly performs the image reconstruction within the CNN framework. The utility of this approach was demonstrated on simulated photoacoustic data from a 64-element semi-circular sensor array. The training and testing datasets comprised of 500 images from a synthetic vasculature phantom and 50 images of an anatomically realistic vasculature obtained from micro-CT images, respectively. The structural similarity index of the PDL-reconstructed images (0.91 ± 0.03) indicated superior image quality compared to those obtained using the iterative reconstruction (0.82 ± 0.09) and CNN-based artifact removal (0.79 ± 0.07).