OPTICS + ULTRASOUND VI

Book of abstracts

Session I – Biomedical

Preclinical Applications of Biomedical Photoacoustic Imaging *Invited talk*

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Photoacoustic imaging (PAI) is a hybrid technique which relies on the generation of ultrasound waves through the absorption of short, low-energy non-ionising laser pulses by light absorbing molecules, such as haemoglobin. By detecting the time-of-arrival of these waves at the tissue surface, a 3-D volumetric absorption-based image of the internal tissue structure can be reconstructed.

The fundamental advantage of PAI is that optical contrast is encoded on to acoustic waves, which are scattered much less than photons. As a consequence, it avoids the depth and spatial resolution limitations of purely optical imaging techniques that arise due to strong light scattering in tissue: with PAI, depths of a few centimetres with scalable spatial resolution ranging from tens to hundreds of micrometres (depending on depth) are achievable. PAI contrast is defined largely by optical absorption. This makes it particularly well suited to visualising the vasculature without the use of contrast agents due to the strong absorption of haemoglobin at visible and near infrared wavelengths.

PAI has found many applications in studying preclinical models of human diseases in a non-invasive manner. In this talk, I will showcase a number of these studies conducted with a high-resolution PA scanner, based an optical Fabry-Perot ultrasound sensor. These include the quantification of tumour response to vascular targeted therapy and the assessment of vascular abnormalities in chronic kidney disease. I will also present results from a new generation of the scanner capable of whole-body imaging.

(2) Concurrent Free-hand Optical Ultrasound and MRI

Mr Fraser Watt, Professor Vivek Muthurangu, Dr Jennifer Steeden, Dr Eleanor Mackle, Professor Adrien Desjardins, Dr Edward Zhang, Professor Paul Beard, Dr Erwin Alles

Optical ultrasound (OpUS) imaging is an emerging paradigm that utilizes fiber-optic ultrasound sources and detectors to perform pulse-echo imaging with flexible, free-hand probes, capable of video-rate imaging. Such probes can be constructed entirely from glass and plastic [1]; as such, these devices are expected to be inherently compatible with electromagnetic imaging modalities such as magnetic resonance imaging (MRI) or X-ray computed tomography. However, to date, this multimodal capability has not been demonstrated.

In this work, a custom 11 m-long fibre-optic free-hand OpUS probe is presented, which converted pulsed excitation light delivered proximally into ultrasound via an OpUS generator membrane deposited distally. Using 3D-printed waveguides [2], the generated ultrasound was elevationally confined to maximise imaging depth. Back-scattered ultrasound was detected by a single fiber-optic Fabry-Pérot detector positioned centrally within the source aperture. The multimodal capabilities of this system were demonstrated by imaging tissue-mimicking phantoms concurrently with OpUS and MRI. Neither modality was affected by the presence or operation of the other, and no detectable reductions in either signal fidelity were observed. This work presents the first real-time demonstration of OpUS imaging simultaneously with MRI and confirms the value of OpUS imaging in multimodality settings.

[1] https://doi.org/10.1016/j.ultras.2021.106514
[2] https://doi.org/10.1109/IUS54386.2022.9958357

(3) Rapid Non-Contact Optical Ultrasound for Biomedical Imaging

Dr Erwin Alles

Biomedical ultrasound imaging conventionally requires physical contact, which prevents application in crowded surgical settings or scenarios at risk of infection or trauma. Recently, the first-on-human non-contact optical ultrasound (NC-OpUS) was presented [1], where excitation light was photoacoustically converted into ultrasound by human skin. Scanning optics were employed to synthesize an imaging aperture. Back-scattered signals resulted in small skin deformations, which were detected optically using a laser Doppler vibrometer (LDV). However, the low photoacoustic conversion efficiency, LDV signal-to-noise ratio (SNR), and laser pulse rate resulted in 2D image acquisition times of several minutes.
Here, a novel NC-OpUS system is presented that enables dynamic, real-time imaging. This is achieved using a high pulse repetition rate laser (2.5 kHz), rapid scanning optics, GPU-accelerated reconstruction, broadband detection (0-24 MHz), and optimized aperture geometries. Importantly, a custom membrane was developed to optimize the LDV SNR and photoacoustic conversion efficiency, together with a method of applying this membrane to skin. Using resolution targets and tissue-mimicking phantoms, this system achieved a spatial resolution of 400 µm by 150 µm, a contrast-to-noise ratio of up to 28 dB, and a frame rate of up to 23 Hz – thus showing great potential for future clinical use.

[1] doi.org/10.1038/s41377-019-0229-8

(4) A colour-changing holographic sensor for quality assurance of therapeutic ultrasound systems

Dr Tatsiana Mikulchyk, Mr John Walsh, Prof Jacinta Browne, Prof Izabela Naydenova, Dr Dervil Cody

Ultrasound therapy, which relies on thermal effects, remains a popular therapeutic modality for physiotherapists and clinicians. The acoustic output of clinical therapeutic ultrasound equipment requires regular quality assurance (QA) testing to ensure the safety and efficacy of the treatment, and that any potentially harmful deviations from the expected output power density are detected as soon as possible. Despite some developments [1], regular QA is still impeded by a lack of inexpensive and straightforward calibration technologies. The objective of this work was to develop a novel, colour-changing holographic sensor to facilitate quick, low-cost regular calibration of the acoustic output of therapeutic ultrasound units.
Holographic reflection gratings with an initial red colour were fabricated in a diacetone acrylamide-based photopolymer film [2] using two beam interferometric techniques at a wavelength of 660 nm. The holograms were then exposed to ultrasound energy from two types of therapeutic ultrasound systems: a sonoporation system and an ultrasound physiotherapy system. A visible change in the colour of the reconstructed hologram from red to green is observed in response to incident ultrasound energy from both systems. The influence of the therapeutic ultrasound insonation parameters (exposure time, ultrasound power density, and proximity to the point of maximum acoustic pressure) on the hologram's response was investigated. It was determined that the immediate and permanent colour change occurs at an approximate switching temperature of 45°C, as measured via thermocouple and infrared camera at the hologram surface. Phase contrast microscope imaging of the film-based holograms shows that, above 45 ^{0}C, the ultrasound-induced temperature rise produces a structural change in the hologram, which manifests as a visible colour change [3]. The area of the colour change region is shown to correlate with the ultrasound exposure conditions.
The suitability of the hologram as a simple and quick QA test tool for therapeutic ultrasound systems output is demonstrated. A prototype ultrasound testing unit which facilitates user-friendly, reproducible testing of the holograms in a clinical setting is also reported.

[1] P. Morris et al "A Fabry-Perot fibre-optic hydrophone for the measurement of ultrasound induced temperature changes", Proc. IEEE Ultrasonics Symposium (2006).
[2] D. Cody, S. Griffin, E. Mihaylova, I. Naydenova, "Low-Toxicity Photopolymer for Reflection Holography", ACS Appl. Mater. Interfaces 8(28) (2016).
[3] T. Mikulchyk, J. Walsh, J. Browne, I. Naydenova, D. Cody, "A colour-changing reflection hologram for quality assurance of therapeutic ultrasound systems", ACS Appl. Mater. Interfaces, 2023 (in press).

(5) Recent Developments in Ultrasonic Tracking using Fibre Optic Ultrasound Sensors

Dr. Sunish Mathews, Prof. Adrien Desjardins

Ultrasonic tracking using a fibre optic ultrasound (US) sensor (FOUS) integrated into a medical device has been shown to have strong potential to improve localization of medical devices in US-guided interventions [1,2]. This technique offers a robust solution for the ongoing issue of poor visualization of medical devices using conventional US. The transmitted signals from the external US transducer are detected optically by the FOUS, which allows for accurate localization of the device (Figure 1a).

Here we present recent innovations with this tracking paradigm. The topics include: a) the capability of the system to dynamically focus US pulses to FOUS within the medical device; the use of bend-insensitive fibre for tracking highly flexible intravascular catheters (minimum curve radius ~ 4.5 mm) for cardiovascular applications; the capability of the system to provide quantitative information on out-of-imaging-plane movement of the device (Figure 1b). At a confluence of optics and ultrasound, ultrasonic tracking has strong potential for clinical translation in many contexts.

1. S Mathews et al, Ultrasound Med Bio, 48(3), 520-529, 2022.
2. S Mathews et al, Med Phys, 50(6), 3490-97, 2023.

(6) Thermal behaviour of fibre-optic ultrasound transmitters: numerical and experimental study

Dr Joanna Coote, Dr Esra Aytac Kipergil, Mr Yi Li, Mr Shaoyan Zhang, Dr Richard Colchester, Dr Semyon Bodian, Prof Adrien Desjardins

Optically generated ultrasound has promising applications in biomedical imaging and therapeutic procedures, but overheating the transmitter can lead to thermal damage to both the ultrasound-generating coating and nearby tissue. Additionally, steam bubble formation can prevent ultrasound transmission. However, the influence of laser parameters and absorbing layer properties on peak temperatures and temperature distributions in and around the optical ultrasound transmitters is not well known.

We have developed a thermal finite element (FE) model of a fibre optic ultrasound transmitter to investigate these relationships. The results were compared with thermal imaging experiments of a candle-soot and polydimethylsiloxane (PDMS) – based fibre-optic ultrasound transmitter.

We found that thermal damage to the coating may occur for pulse energies above 140 µJ, and at a pulse repetition rate of 1 kHz, the temperature of the surrounding medium may exceed 100 °C with a coating absorption coefficient of 124 mm^-1.

The temperature rise in the coating depends linearly on the pulse energy and coating absorption coefficient, with higher pulse repetition frequencies leading to higher temperatures at all locations. Combining higher absorption coefficients with lower pulse energies mitigates temperature elevations in the coating.

These findings point to optimisation routes for better performance and greater patient safety.

Session II – Novel and ultrafast methods

(7) Time-domain Brillouin scattering: A tool for elastic property characterization, three-dimensional imaging, and real-time monitoring of transient processes *Invited talk*

Samuel Raetz, Vitalyi E. Gusev, Nikolay Chigarev, Sathyan Sandeep

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The time-domain Brillouin scattering (TDBS) technique [1] is a rapidly advancing all-optical experimental approach that uses ultrafast laser pulses to generate and monitor the propagation of coherent acoustic pulses (CAPs) within transparent materials. Within TDBS, the absorption of pump laser pulses by a light-absorbing layer attached to a transparent sample initiates the CAPs propagation in a medium with a length ranging from tens to hundreds of nanometers. This propagation is monitored using time-delayed probe pulses. The interferences between portions of the probe light, reflected by stationary interfaces and scattered by the propagating CAPs, are detected by a photodetector. These interferences yield a time signal with characteristic oscillations, known as Brillouin oscillations.

In heterogeneous materials (such as polycrystals or materials with property gradients), local variations of the elastic, optical, and/or photoelastic properties can be tracked all along the CAPs propagation, providing depth-dependent insights. The use of an experimental setup founded on asynchronous optical sampling enables signal acquisition over a time span ranging from seconds to minutes. Consequently, this technique offers the potential for three-dimensional imaging with sub-optical axial (along the direction of CAP propagation) and optical lateral resolutions.

This presentation will encompass the recent experimental advances achieved at the Laboratoire d'Acoustique de l'Université du Mans (LAUM) in the application of TDBS to characterize the elastic properties of complex materials within diamond anvil cells [2-3] or thin films [4], three-dimensional imaging of polycrystalline materials [5-7], and real-time monitoring of transient processes such as phase transitions [8], light-induced modifications [9], and epoxy curing. The experimental observations will be enlightened by a novel analytical theory that we have recently developed [7,10]. This theory accounts for the non-collinear propagation of Gaussian beams of probe light and acoustic waves, in addition to the inclination of materials interfaces.

Finally, we will explore the potential avenues for further advancing TDBS-based imaging that emerge from the synergy of experimental findings and theoretical considerations.

Acknowledgements

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[1] V. E. Gusev and P. Ruello, Appl. Phys. Rev. 5, 031101 (2018). [2] M. Kuriakose et al., Phys. Rev. B 96, 134122 (2017). [3] S. Raetz et al., Phys. Rev. B 99, 224102 (2019) [4] S. Sandeep et al. Nanomaterials 11, 3131 (2021) [5] T. Thréard, et al., Photoacoustics, 23, 100286 (2021). [6] S. Sandeep, et al., J. Appl. Phys. 130, 053104 (2021). [7] S. Sandeep et al., Photoacoustics, in press (2023). [8] M. Kuriakose, et al., New J. Phys. 19, 053206 (2017). [9] S. Sandeep, et al., Nanomaterials 12, 1600 (2022). [10] V.E. Gusev et al., arXiv:2107.05294 [cond-mat, physics:physics], under review in Photoacoustics journal (2023).

(8) Apertures for Generating Spatial Superoscillations of Coherent Acoustic Phonons

Monty E. Clark, Keith A. Benedict, Khouloud Sellami, Andrey V. Akimov, James Bailey, Richard P Campion, and Anthony J. Kent

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In this presentation we discuss the approaches we have taken to design superresolving devices for phonons by exciting an opto-acoustic transducer with a spatially modulated femtosecond-pulsed light beam.

Superoscillation is an interference effect whereby, in specific regions, functions can oscillate faster than their fastest Fourier component. This can be exploited to achieve superresolution, where the diffraction limit may be broken, as has been demonstrated in optical imaging[1].
Our objective was to design an array of standard apertures (holes, discs, annuli) in an optically opaque mask such that the overall diffraction pattern obtained by illuminating the mask with light of a given wavelength generates a superoscillating optical field at the opto-acoustic transducer thereby generating a superoscillating acoustic strain field. Our route to solving the inverse problem of finding the required positions for the apertures in the mask was by aiming to generate a far-field pattern within the broad class of superoscillations constructed by Aharonov[2] with well-characterized Fourier components. A simulation of the acoustic superoscillations generated by a grating pattern, Figure 1(a), is shown in Figure 1(b).
In the pump-probe experiments, gold shadow masks corresponding to the aperture designs were fabricated by optical lithography on the surface of a 5 GHz Ga(Al)As superlattice transducer, Figure 1(c). Where the pump light fell on gold it was reflected leaving a spatially modulated light intensity distribution on the transducer. The spatial distribution of the 5 GHz phonon signal intensity on the opposite side of the 450 micron-thick GaAs substrate was measured using a scanning probe beam, Figure 1(d).
Further work is being done to generalise the solving process by using overlap integrals to resolve both aperture widths and offsets.

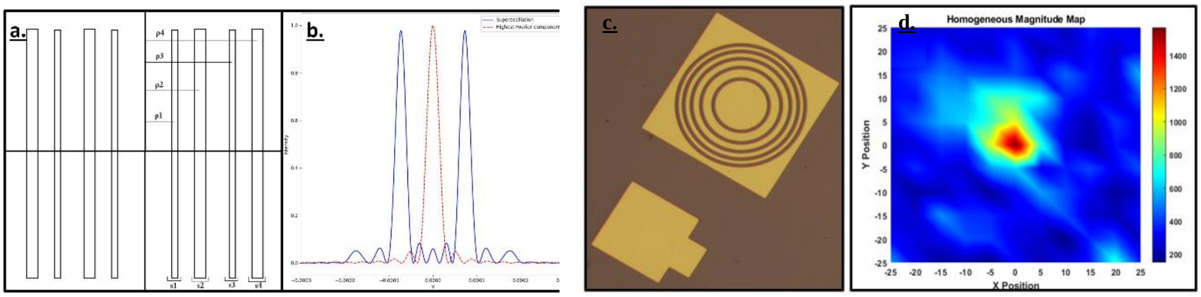

Figure 1: (a) Designs for a diffraction grating superoscillating aperture array. **(b)** Simulated results in natural units for the design in **(a)** with a phonon wavelength of approximately 1µm. The orange dashed line shows the simulated intensity distribution of a single slit compared to the solid blue line of the superoscillating aperture array. As can be seen there are features smaller than the highest Fourier component, a superoscillation. **(c)** A gold shadow mask for the opto-acoustic transducer in the shape of the superoscillating concentric annuli aperture array described by Torlado di Francia[3], examined by Cox et al[1] and produced by us using optical lithography. **(d)** Results from an initial investigation of the design in **(c).** Due to noise and acoustic anisotropy, it is difficult to resolve the superoscillation.

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(9) Picosecond ultrasonics for cell imaging and characterisation

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Characterization of the elasticity of biological cells is emerging as a way to study cell biology. Cell mechanics are related to many aspects of cellular behaviour, where applications in research and medicine are broad. Traditional methods to study elasticity are often limited since they require physical contact or lack resolution. From the methods available for the characterization of elasticity,those relying on high frequency ultrasound (phonons) are among the most promising. Acoustics offers an intriguing alternative for biocompatible, high resolution imaging as the acoustic wavelength at the GHz in biological samples is typically sub-optical. However, the attenuation of sound posed challenges in the implementation of piezoelectric transducers as these are challenging to fabricate, wire and use at the required bandwidth. Also, short working distances (40µm) and wide microscope heads (1cm) are difficult to implement. Here we present new developments of picosecond ultrasonics for cell imaging and characterization,particularly for methods based on Brillouin scattering and nanoparticles. We discuss how these contribute to the field in terms of capabilities such as lateral, axial resolution, contrast, and biocompatibility. We present preliminary results on several use cases that demonstrate applicability of the methods presented.

(10) New avenues for ultrasound detection with Fabry Perot resonators

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Fabry Perot (FP) resonators have long been a workhorse for optical detectIon of ultrasound, finding application in photoacoustic imaging and spectroscopy giving high bandwidth and non contact operation. Here we present two FP resonators with distinct advantages. A conventional FP operates primarily by the dimensional change induced by the incident sound wave as shown in fig 1. In our first design we use total internal reflection to form the upper reflector. This has two very significant effects (i) as the polymer layer is uncoated very soft polymers can be used on which it is difficult to deposit additional layers. These soft materials like PDMS greatly enhance the sensitivity and (ii) since the polymer is in contact with the couplant the sensor is sensitive to a second mechanism namely the variations of refractive index in the couplant induced by the sound wave. This gives a mechanism with greatly enhance bandwidth since the the sound wave is sensed within the evanescent wave arising from the total internal reflection. Secondly, we show that grating reflectors form a bimodal FP (Fig2) with coupling between the modes. This gives complex behaviour with potential for ultrahigh Q and sensitivity as indicated by the arrows of Fig3.

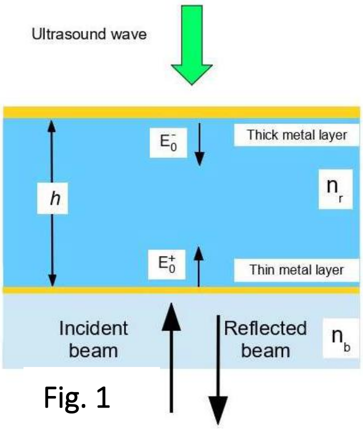

Fig. 1

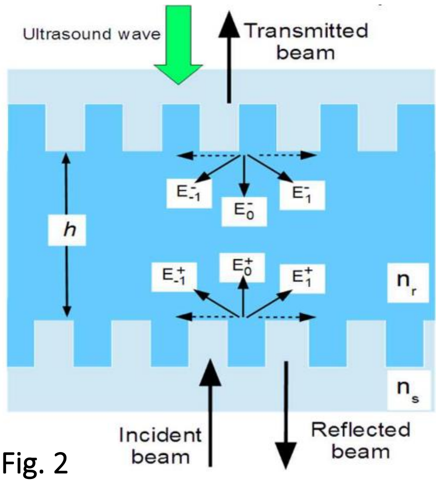

Fig. 2

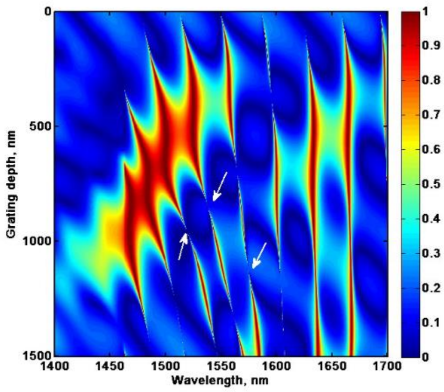

Fig. 3

(11) Laser-based resonant ultrasound spectroscopy pushes the limits of modal analysis

professor Hanuš Seiner, Mr. Juraj Olejnak, Dr. Michaela Janovska, Dr. Petr Sedlak

Modal analysis is well-established method for characterization of mechanical systems (construction parts or samples of materials) based on their spectra of elastic vibrations. Typically, the analysis is limited to the first few tens of modes, because at higher mode numbers, the modal shapes become very complex, and also the numerical tools used to predict the resonant frequencies loose their accuracy.
In this contribution, we will show that when using laser-ultrasonics and simple geometries of the vibrating objects, the limit of the applicability of the modal analysis can be pushed to significantly higher mode numbers. Resonant modes with numbers above 400 can be reliably detected and identified in the spectrum, provided that the numerical model of the vibrations is correctly fitted to the experimental data. The highest modes are particularly sensitive to the dimensions of the sample, or its crystallographic orientation in case of an anisotropic material, which opens new possibilities for applications of a modal analysis. As for an example, we utilize this type of analysis for characterization of low-symmetry crystals of twin-microstructured Co-Cr-Ga-Si magnetic shape memory alloys.

Session III – NDE & materials

(12) A novel thickness measurement method for extreme environments using laser ultrasound in the thermoelastic regime

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The standard ultrasonic thickness measurement method is enabled by the strongly normally-directed directivity pattern of longitudinal acoustic waves emitted by piezoelectric transducers. Deploying such transducers is not, however, possible in certain extreme environments, where non-contact laser ultrasonic inspection is instead required. Thermoelastic excitation of ultrasound, however, generates very little ultrasonic amplitude normal to the illuminated surface in metals, with the highest amplitude waves instead emitted in lobes angled away from the surface normal. This directivity pattern is not compatible with the standard ultrasonic thickness measurement method since no ultrasonic amplitude will be reflected back to the source point. In this work, techniques used in reflection seismology have been applied to the problem of measuring back-wall thickness using thermoelastic laser ultrasound. Capturing a set of A-scans at a fixed detection point for a periodic, linear array of source points with increasing surface off-set (x) from the detection point enables the normal moveout hyperbolae associated with specular back-wall reflections to be mapped. Back-wall thickness and ultrasonic speed are determined simultaneously via straight line fitting to the echo peaks in an x2-vs-time2 plot. This methodology is presented for both simulated and experimental data sets, and its accuracy and limitations are discussed.

(13) With (ultra-)transient grating spectroscopy towards full elasticity characterization

Tomas Grabec, Kristyna Repček, Jakub Kušnír, Pavla Stoklasová, Petr Sedlák, Hanuš Seiner

Transient grating spectroscopy (TGS) with differential heterodyne detection setup offers extremely high sensitivity to the out-of-plane displacement and thermal diffusivity. With a detailed angular scan of elastically anisotropic samples, an angle-velocity map of TGS frequency spectra can be drawn, in which certain weak features behave in a specific manner differentiating them from noise – and in agreement with limiting bulk-wave velocities. We identified two sources of the effect: Modulation of white noise connected to the thermal excitation by acoustic modes able to either strengthen or diminish the noise level, and surface-skimming waves, creating surface resonances in the first tens of nanoseconds after the excitation, i.e., more than an order of magnitude faster than true surface modes, thus forming an ultra-transient grating – hence, the ultra-transient grating spectroscopy (UTGS). With such a detailed information provided by the UTGS, full elastic tensor of cubic or hexagonal materials can be determined from a single-surface measurement with a numerical procedure solving the inverse problem. With two surface scans, even orthorhombic elasticity with nine independent constants can be fully determined.

(14) All- optical laser ultrasound tomography for biomedical imaging using deep neural networks for image reconstruction

A. Al Fuwaires, D. Pieris, G. Davis, P. Lukacs, H. Mulvana, K. Tant, T. Stratoudaki

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Laser ultrasound (LU) is a non-contact, couplant-free imaging technique that uses non-ionizing radiation. These are advantages over other imaging modalities such as X-rays and conventional, transducer ultrasonic imaging. In addition, LU assures repeatability and lends itself well to automation, compared to manually delivered ultrasound examination, making the technique a prime candidate for tomography applications.

We propose an all-optical system capable of tomographic imaging of biomedical related samples. Such a system could be used for breast tomography. The aim of the presented study is to demonstrate laser ultrasound imaging of a gelatin phantom situated in water, recreating a velocity map of the tested material by way of a deep neural network (DNN).

The investigated area was a tank filled with water and the phantom with areas of varying speed of sound. Ultrasonic wave generation was achieved by a laser incident on a glass plate coated with candle soot nanoparticles-polydimethylsiloxane, while ultrasonic detection was achieved via a laser incident on a glass plate coated with aluminum to assure reflectivity. Signals were acquired in a through transmission setup and a time-of-flight matrix (TOF) was created. A DNN was trained using simulated data and was used to reconstruct a velocity map of the investigated region using the TOF matrix as input.

(15) Single shot simultaneous determination of sound velocities and thickness of plates with laser-ultrasound

Clemens Grünsteidl, Georg Watzl

Single point ultrasonic measurements of the thickness of a sample generally require its sound speed as a priori knowledge, or vice versa. There are situations in which this requirement is a limitation. For example, the sound speed is influenced by an unknown temperature, and thus a precise thickness measurement is not possible. This is especially perturbing in laser ultrasound applications in metal processing environments, with the technical possibility to measure contact-free on hot samples as one major advantage of the technique.

To overcome this limitation, we use laser-ultrasound to simultaneously generate and detect specific, discrete frequencies of the response spectrum of a plate, which is composed of a superposition of Lamb modes. We therefore apply a periodic line excitation pattern of known periodicity to force a response of the fundamental Lamb mode (approximating a surface acoustic wave, SAW) at a frequency corresponding to the wavelength forced by the pattern. In addition, the overall size of the excitation pattern is chosen small enough to simultaneously couple into (at least two) zero-group-velocity plate resonances appearing at two additional frequencies in the response spectrum. From the pattern periodicity and the 3 measured frequencies we can calculate the longitudinal- and transverse sound velocities of the plate and its thickness.

We demonstrate the method for different engineering metals and show its capabilities to compensate for temperature-induced changes of sound velocities while measuring thickness. We discuss the optimum pattern, and the sensitivity of the method to different sources of errors, such as defocusing or a deviation from ideal samples. The beauty of the method is that it combines an externally forced interference of the fundamental mode with intrinsic resonance phenomena of the plate. From the measured frequencies, the local sound velocities and thickness of the plate are found. Considerations on signal-to-noise ratio show that this can be achieved in a single shot measurement.

(16)Ultrasonic imaging of volumetric defect using diffuse signals acquired from a laser vibrometer

Jun Li

Laser induced ultrasonic arrays have been used for defect detection and have advantages of being non-contact, and able to cope with complex geometry and harsh environments. However, the detection speed is limited by slow data acquisition, as the combinations of every transmitting and receiving sampling points are required to build up a full matrix capture (FMC) array data. This issue becomes even more challenging when detecting volumetric defect using a two-dimensional array. In this paper, a single conventional transducer is used to send ultrasound into a sample at an optimized location, while a laser vibrometer is used to acquire data at a prescribed set of 2D array element locations. The FMC array data for the 2D array is recovered from the acquired signals by cross-correlating pairs of acquired signals in their wave diffuse regimes. Compared to regular FMC using laser generation at each array element location, this approach results in a reduction in the number of acquired signals by a factor equal to the number of sampling points. The proposed method is demonstrated for imaging different types of defects, including sided-drilled-holes and flat bottom holes. The imaging performance is compared with the images obtained from conventional matrix ultrasonic arrays and laser induced ultrasonic arrays. It is shown that the proposed method can achieve the same image quality as conventional matrix ultrasonic arrays.

(17) Finite element and analytical modelling of laser ultrasound source directivity

Miss Xin Tu, Dr Jie Zhang, Dr Alberto Gambaruto, Prof Paul Wilcox

Laser induced phased array (LIPA) is a special inspection arrangement of ultrasonic non-destructive evaluation, which uses laser ultrasound (LU) as the ultrasound transduction method and synthesizes phased arrays in post-processing. LIPA benefits from the flexible array layout due to optical scanning, and also the imaging ability of conventional phased array testing. When designing the inspection, the directivity of the LU source is an important factor to consider for optimising the scan strategies to minimise the scan time and to maximise the defect detection performance. A general strategy for modelling the LU source using finite element (FE) simulation is proposed in current work. The LU source is first represented by Gaussian distributed heat source in Multi-physics models, and then by equivalent elastodynamic loadings in elastodynamic models. The FE modelling strategy is benchmarked against the analytical solution for surface force dipole on isotropic elastic half-space, and compared to the experimental measurements in aluminium sample. The application of the FE modelling strategy is then extended to buried sources in anisotropic heterogeneous materials and compared with measurements from carbon fibre reinforced polymer (CFRP) samples. The equivalent elastodynamic model enables the analytical solution in complex materials to be derived.

(18) Automated defect detection in ultrasonic images from a reconfigurable Laser Induced Phased Array

Don Pieris, Peter Lukacs, Panagiotis Kamintzis, Geo Davis and Theodosia Stratoudaki

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Laser Induced Phased Arrays (LIPAs) LIPAs are synthetic arrays, based on the principles of laser ultrasonics (LU). Unlike transducer-based ultrasonic probes, LU is a completely non-contact method that can operate remotely, does not require any couplant and can adapt itself to complex geometries, addressing some current limitations of transducer-based ultrasonic arrays. In LIPAs, data acquisition is carried out by one generation and one detection laser, scanned independently of each other, allowing any arbitrary array design,

with decoupled generation and detection layouts. Following data acquisition, an imaging algorithm (e.g. the Total Focusing Method (TFM) delay-and-sum algorithm) is used. This paper presents the automation of a novel adaptive acquisition strategy, the Selective Matrix Capture, wherein the array characteristics are optimised and adapted to the needs of the imaging case. This is achieved by a two-stage process, with the purpose of the first stage being to rapidly identify regions of interest, followed by the second stage, where the array parameters are optimised for accurate defect characterisation. A criterion is presented for switching from the first to the second stage. It is based on the distribution of the intensity of pixels in the produced TFM image in order to stop the iterative process and proceed to array optimisation. The paper evaluates the performance of the automated system based on a large area inspection of an aluminium sample with a 1mm side drilled hole simulating a defect.

Challenges in measuring mean surface acoustic wave velocity using laser-ultrasound

Georg Watzl, Clemens Grünsteidl

The measurement of surface acoustic wave (SAW) velocities has emerged as an attractive tool for assessing elasticity [1], properties of coatings [2], and grain structures [3] of metals. In our research we combine SAW velocity measurements with measurments of resonance frequencies in plates, allowing for simultaneous thickness and sound velocity determination [4]. Here we analyze different methods and challenges of laser ultrasound (LUS) based SAW velocity measurements. We address material, experimental and signal processing aspects that affect accuracy and precision. In this context, we review theoretical models of surface displacement after pulsed laser line excitation [1, 5], which surprisingly show different results. With this contribution we seek to elucidate the intricacies of SAW velocity measurements, offering potential solutions to enhance or estimate accuracy and reliability in non-destructive materials characterization.

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Forward simulation model of photoacoustic imaging of photochromic contrast agent for tracking CAR-T cells in cancer immunotherapy

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Quantifying the spatial concentration of CAR-T cells in cancer immunotherapy remains challenging. The use of photoacoustic imaging and a reporter gene has the potential to address this challenge. Cells expressing the reporter gene produce photochromic proteins that provide optical-absorption contrast characterised by a distinct temporal signature, enabling the target cell population to be identified from time series-images. Artificial intelligence (AI) has the potential to optimise the complex workflow of analysing the imaging data for CAR-T cell tracking and quantification, but extensive high-quality data is required for training and validating AI models. We present a numerical framework for forward data generation, where the photon transport and acoustic pressure generation are modelled in three-dimensions via Monte Carlo simulations [1] while employing a time-dependent model of the optical absorption coefficient. The three-dimensional acoustic forward modelling, detection and two-dimensional initial pressure reconstruction are implemented in k-wave [2]. This framework was validated by comparing time-series photoacoustic images of a numerical phantom with time-series photoacoustic images of an experimental phantom.

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Key Words: photoacoustic Imaging; CAR-T cell imaging; forward data generation

Lensing of Coherent Phonons in Pump-Probe Experiments

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We explore the use of spatial light modulation with Fresnel zone plate apertures to focus sound waves in pump-probe laser ultrasonic experiments. A 5 GHz GaAs/AlAs superlattice (SL) transducer is employed. Gold shadow masks corresponding to the aperture designs for 1 micron acoustic wavelength are fabricated on the transducer surface [Figure 1]. Near-IR pump light is reflected from the gold-coated areas, resulting in a spatially modulated light intensity distribution on the SL transducer. The spatial distribution of the 5 GHz phonon signal intensity on the opposite side of the GaAs substrate is measured using a scanning probe beam. The lens aperture focuses the phonons, resulting in a narrower intensity distribution than the original pump spot. This technique shows promise for generating focused coherent phonons by spatially modulating the pump laser intensity with a Fresnel lens aperture. Using a spatial light modulator, such as a DMD, could expand its applications in laser ultrasonics, enabling high strain amplitudes without exceeding the transducer's damage threshold.

Picosecond ultrasonics of two-dimensional nanolayers

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Two-dimensional materials (2D) have strong intralayer chemical bonds and weak interlayer van der Waals (vdW) interaction. This highly anisotropic feature gives rise to rich phonon modes covering acoustic to THz frequencies. Their rich physical properties and phonon resonances provide an ideal platform for phonon mediated mechanisms, in which a quantum of energy can be exchanged between different elementary excitations through phonon.
However, thorough understanding and engineering of their phonon properties is required to achieve this challenging task. We study 2D materials using pump-probe technique with microscope objective for imaging ultrasonic signal with submicrometer resolution [1-4]. Using the elastic contact between MoS_2 and the nanograting, we generate and detect propagating coherent phonon modes up to 40 GHz and immobile hybrid flexural phonons up to 10 GHz [4]. We demonstrate picosecond ultrasonics (PU) in probing of 2D materials and their interfaces, and revel new type of 2D periodic phononic nanoobject, a flexural phononic crystal.

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Imaging material elasticity using spatially resolved acoustic spectroscopy (SRAS) ++

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Measuring the single-crystal elastic constants of polycrystalline materials has important engineering applications. This information is critical for predicting the macroscopic mechanical behavior of materials and designing new materials with tailored mechanical properties.

A new method for measuring the single-crystal elastic stiffness matrix of polycrystalline materials is presented. It builds on the capabilities of SRAS, a laser ultrasound technique for measuring the surface acoustic wave (SAW) velocity of a material. Combining measurements from multiple acoustic propagation directions with the elastic constants from literature, it is possible to determine the grains' orientation. This paper details recent work for measuring the single-crystal elastic constants of polycrystalline materials combining SRAS with an inverse solver to extract both the orientation and elasticity from the SAW measurements.

A CMSX-4 sample was measured with SRAS. If the literature elastic constants are used to determine the orientation of the grains, the orientation values found do not match those from EBSD, while the results by SRAS++ method is significantly improved. This sample had undergone heat treatment and this process has clearly modified the elastic properties of the sample.