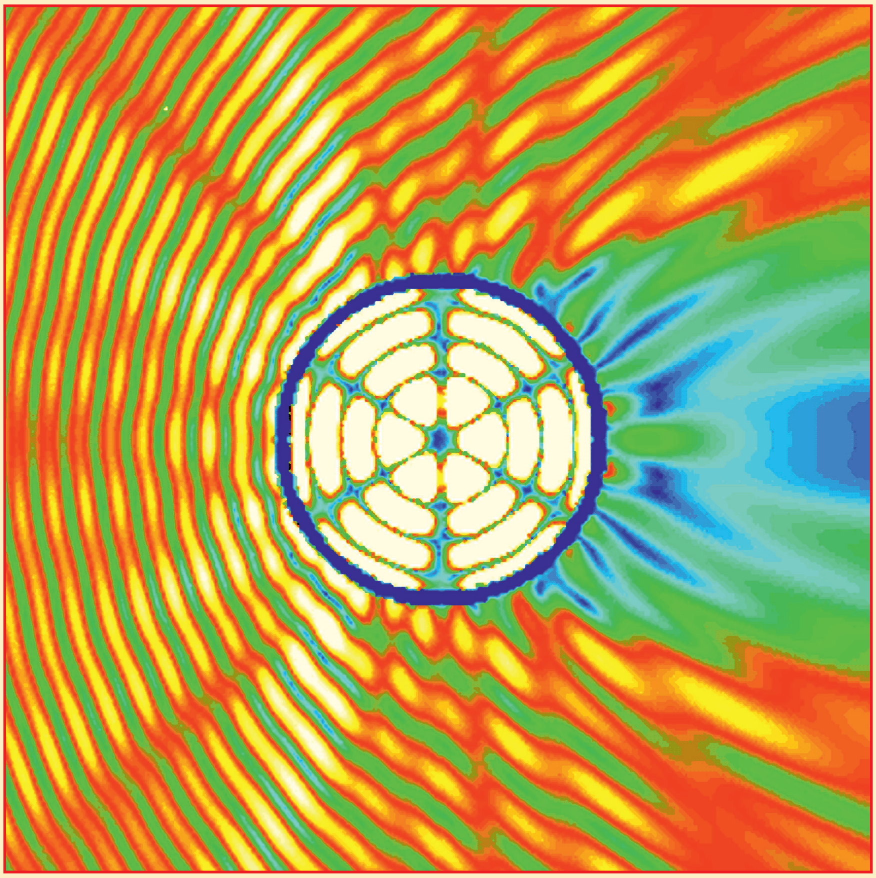
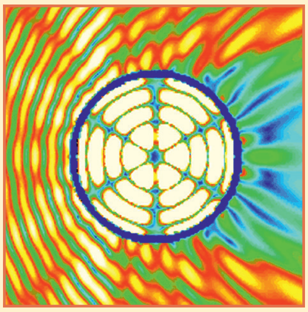
Abstract Booklet



Anglo-French Physical Acoustics 2020

15–17 January 2020
Selsdon Park Hotel, Surrey, UK

IOP Institute of Physics



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Programme

Wednesday 15 January

Location: Sanderson Suite

12:00	Registration *Sanderson Lobby*
12:00	Lunch *1042 Restaurant*
13:25	Welcome Address
13:30	(Invited) **Translational ultrasound – of mice and men** Carmel Moran, The University of Edinburgh, UK
14:00	**Simulation and experimental propagation of guided waves in cortical bone** Fiona Somoreau, Université de Bordeaux, France
14:20	**A controlled study of pre-osteoblast proliferation and PGE2 up-regulation after exposure to low intensity pulsed ultrasound** Jill Savva, University of Glasgow, UK
14:40	**A direct volumetric image reconstruction algorithm for 3D ultrasound computed tomography of the breast** Ashkan Javaherian, University College London, UK
15:00	(Invited) **Double Bubble: The dual use of bubbles and droplets in medical diagnosis and therapy** Brian Fowlkes, University of Michigan, USA
15:30	Coffee and Posters *Terrace Pantry*
16:00	**Reverberant shear wave elastography in a preclinical mouse tumour model** John Civale, The Institute of Cancer Research, UK
16:20	**Listening to oxygenation: deep learning for estimating vascular sO2 with photoacoustic imaging** Ciaran Bench, University College London, UK
16:40	**Characterization and technical validation of a multi-wavelength LED-based photoacoustic/ ultrasound imaging system** James Joseph, University of Cambridge, UK
17:00	(Invited) **Characterizing spatiotemporal dynamics of fetal brain development from ultrasound images** Ana Namburete, University of Oxford, UK

Thursday 16 January

Location: Sanderson Suite

08:40	**Initial results from a sparse sampling approach for distributed acoustic sensing** Robert Ellwood, OptaSense, UK
09:00	**Monitoring sea ice with seismic noise** Ludovic Moreau, Université Grenoble Alpes, France
09:20	**Scattering of acoustic evanescent waves by spherical resonant objects** Ludovic Alhaïtz, Université de Bordeaux, France
09:40	**Frequency dependence of surface acoustic wave swimming** Caroline Pouya, University of Exeter, UK
10:00	(Invited) **Elastic Metamaterials** Richard Craster, Imperial College London, UK
10:30	Coffee and posters *Terrace Pantry*
11:00	(Invited) **A two-dimensional Su-Schrieffer-Heeger acoustic network: observation of topological edge waves** Vincent Pagneux, CNRS, LAUM, Le Mans Université, France
11:30	**Metallic microparticles as key elements for the study of ultrasonic wave transport through strongly resonant scattering media** Fanambinana Delmotte, Université de Bordeaux, France
11:50	**Acoustic radiation torque in soft solids generated by vortex beams** Diego Baresch CNRS, Université de Bordeaux, France
12:10	**A model to predict the elastic field radiated by a magnetostrictive patch transducer into an omnidirectional waveguide** Guillaume Cousin, CEA-LIST, Université Paris-Saclay, France
12:30	***In situ* bubble dynamics controlled by an acoustical trap** Diego Baresch, CNRS, Université de Bordeaux, France
12:50	**Origin of the popping: sound a capillarity acoustic resonator** Mathis Poujol, CNRS, Institut d'Alembert, Sorbonne Université, France
13:10	Lunch and posters *1042 Restaurant*
14:00	(Invited) **The role of cavitation in therapeutic ultrasound** Lawrence Crum, University of Washington, USA
14:30	**Pressure-modulated shockwaves for inducing mechanical tissue destruction** Ki Joo Pahk, Korea Institute of Science and Technology, South Korea

14:50	**OptimUS: an open source general purpose ultrasound simulation platform** Pierre Gélat, University College London, UK
15:10	**Applications of intensive HIFU simulation based on surrogate models using the CIVA healthcare platform** Sylvain Chatillon, CEA-LIST, Université Paris-Saclay, France
15:30	Coffee and posters *Terrace Pantry*
16:00	**Fetal acoustics: a computational study** Reza Haqshenas, University College London, UK
16:20	**Design and construction of a low-frequency ultrasound system for brain imaging** Javier Cudeiro, Imperial College London, UK
16:40	**Full waveform inversion for ultrasound tomography of the brain: an uncertain approach to finding the correct starting parameters** Oscar Bates, Imperial College London, UK
17:00	**Multi-band finite element simulation of ultrasound absorption by soft tissue** George West, Imperial College London, UK
17:20	**Measurement of the temperature-dependent output of a PZT transducer** Marina Bakaric, University College London, UK
19:00	Conference Dinner *Cedar Suite*

Friday 17 January

Location: Sanderson Suite

08:30	**Local evaluation of elastic moduli by ultrasounds. Towards the mapping of mechanical properties of adhesively-bonded joints** Victor Gayoux, Université de Bordeaux, France
08:50	**A semi-analytical finite element method for the forced response and surface wave propagation in multi-layered solid spheres** Matthieu Gallezot, Université de Nantes, France
09:10	**Quantitative ultrasound imaging under anisotropic conditions: application and perspectives for wood evaluation** Luis Espinosa Moreno, CNRS-LMA, Université Aix Marseille, France
09:30	**Guided wave NDT: the contributions of numerical prediction and computed tomography** William Cailly, CNRS-LMA, Université Aix Marseille, France
09:50	**Low power EMATs, coded excitation and measurement of SNR during probe motion** Frederic Cegla, Imperial College London, UK

10:10	**Surface wave methods to monitor fatigue degradation in steel components** Georgios Sarris, Imperial College London, UK
10:30	Coffee and posters *Terrace Pantry*
11:00	(Invited) **Ultrasound evaluation of bone fragility** Quentin Grimal LIB, Sorbonne Université, France
11:30	**Optimised data acquisition for laser induced phased arrays** Peter Lukacs, University of Strathclyde, UK
11:50	**Laser-ultrasonics-based inspection of cracked or adhesively-bonded plates with zero-group-velocity (ZGV) Lamb modes: imaging and characterization** Samuel Raetz, CNRS-LAUM, Le Mans Université, France
12:10	**Towards a more accurate contact law for describing the nonlinear response of closed rough interfaces** Dorra Nouira, Université de Bordeaux, France
12:30	**Particles levitation in air using wideband ultrasonic waves** Dmitry Sukhanov, Tomsk State University, Russia
12:50	Lunch and depart *1042 Restaurant*

Poster programme

P1	**Weak-dispersion and high-efficiency multilayer space-coiling metamaterial** Weipeng Tang, Huazhong University of Science and Technology, China
P2	**Gradient space-coiling metamaterials for high-transmission negative refraction** Shuaishuai Tong, Huazhong University of Science and Technology, China

Joint session with the Medical Physics group

(Invited) Translational ultrasound - of mice and men

Carmel Moran

The University of Edinburgh, UK

Preclinical ultrasound scanners have been commercially available for the last twenty years and have become an integral and versatile part of the preclinical imaging laboratory gaining increasing traction in longitudinal studies for which functional and physiological murine data is required at multiple time-points. Ultrasonic microbubbles, manufactured in-house or commercially available, can provide information on perfusion of murine organs. In addition, these microbubbles can be used to facilitate temporary opening of the blood brain barrier when insonated at high acoustic pressures through the skull. In this presentation, the impact of the size of bubble and also the shell characteristics on the size and duration of blood brain opening will be presented.

Simulation and experimental propagation of guided waves in cortical bone

Fiona Somoreau, Ollivier Tamarini, Corinne Dejousi, Dominique Rebièrei, Simon Hemour and Michel Castaings

Université de Bordeaux, France

Ultrasonic wave propagation in cortical medium is of interest for various biomedical purposes. As a matter of fact, wave-guiding of energy along bones of various geometry is nowadays a research field of interest with application to sensing and stimulation. Since performance level is subject to good understanding of the medium parameters (geometry, thickness, topology, density, viscoelasticity …), the study intends to characterize the generation and propagation of guided waves in a known phantom bone. To limit the number of solutions, the present study focuses on low frequency propagation, where mode analysis is easier.

In order to build an accurate numerical model, the material mechanical properties are first characterized. 2.5D Semi-Analytical Finite Element (SAFE) method is then used to find dispersion curves and mode shapes in the cross section of the simulated bone at low frequency (~50kHz). A 3D FEM simulation is run to confirm the 2.5D simulation results and further assess the attenuation coefficient of the propagating guided modes. The simulated results are finally confronted to experimental measurements. A resin rib (a=6.5, b=3.5mm, L=220mm) is excited with a mechanical pulse produced by an attached PZT element and the 3D resulting displacements are measured along the bone surface and used as input data to a 2D FFT signal analysis to build the dispersion diagram.

Keywords: Ultrasounds – Bone – Dispersion Curves – Mode shapes – FEM

A controlled study of pre-osteoblast proliferation and PGE2 up-regulation after exposure to low intensity pulsed ultrasound

Jill Savva[1], Margaret Lucas[1] and Helen Mulvana[2]

[1] University of Glasgow, UK, [2] University of Strathclyde, UK

Background

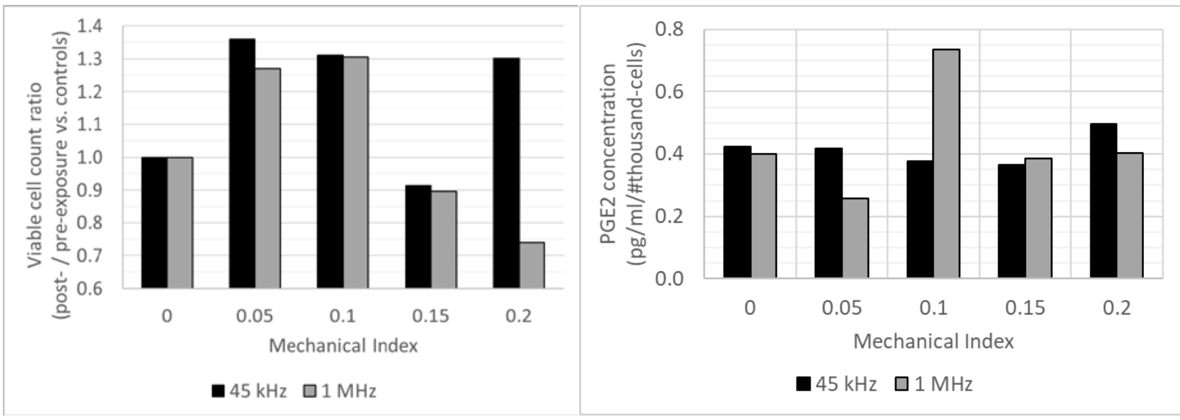
Low Intensity Pulsed Ultrasound (LIPUS) is a recognised treatment for fractured bone but the mechanisms involved are not well understood. Past *in vitro* studies suggest LIPUS stimulates mechanotransduction pathways to increase proliferation and up-regulate cellular markers indicative of healing, e.g. Prostaglandin-

E2 (PGE2)[1]. However, the acoustic field was often not well characterised and inconsistent between studies. We developed a controlled *in vitro* ultrasound exposure method and tested effects of LIPUS on pre-osteoblast proliferation and PGE2 production, at low and high frequency (45 kHz, 1 MHz) and Mechanical Index 0 to 0.2.

Methods

A novel culture vessel, the biocell, was developed for *in vitro* LIPUS exposure, comprising a 3D-printed circular frame bounded by 6μm mylar (Goodfellow), creating an acoustically-transparent window and cell growth surface. Ten biocells were seeded with MC3T3-E1 cells (25,000/cm^2) and incubated for 24 hours. Cells were stained and imaged by fluorescence microscopy, immediately prior to 20-minute LIPUS exposure in a tank of sterilised water at 34±1°C. Two transducers provided LIPUS fields at 45 kHz and 1 MHz, pulse width 200 µs, repetition rate 1 kHz and MI 0.0 to 0.2 (0.05 steps). LIPUS fields were pre-characterised with 0.5 mm and 2 mm needle hydrophones (Precision Acoustics). After 20-hours incubation, media was collected and fluorescent imaging repeated. PGE2 concentration in the media was assessed by ELISA (Abcam) and plate reader (Tecan). Viable cells pre- and post-exposure were compared with controls to assess proliferation. To maximise sample size, cells were counted in areas exposed to maximum MI (centre) and lower MI (off-centre).

Results



(a) *(b)*

Figure 1: (a) Ratio of viable cells post-/pre-exposure vs. controls and (b) PGE2 concentration 20-hours post-exposure, at 45kHz and 1MHz and MI = 0.0 (control) to 0.2

Conclusion

At exposure to 1 MHz LIPUS, cell proliferation and PGE2 concentration peaked at 0.1 MI. The effects of exposing cells to 45 kHz LIPUS were prone to variation but PGE2 was increased at 0.2 MI. We hypothesise that the shorter rise time of the 1MHz pulse produces a step-change in radiation force which stimulates the mechanotransduction pathways. Future work will test this theory and investigate 45 kHz LIPUS at MI greater than 0.2.

[1] Padilla, F, et al., *Stimulation of Bone Repair with Ultrasound*, Therapeutic Ultrasound, Eds J.-M. Escoffre and A. Bouakaz, 2016, Springer International Publishing: Cham. p.385-427.

A direct volumetric image reconstruction algorithm for 3D ultrasound computed tomography of the breast

Ashkan Javaherian, Ben Cox and Felix Lucka

University College London, UK

Ultra-sound Computed Tomography (USCT) is an attractive method for detection and monitoring of cancerous lesions in the breast as it uses no ionising radiation and does not require painful breast compression. Image reconstruction algorithms for USCT can be broadly divided into those based on ray-tracing and model-based full-wave inversion. There are two reasons to use ray-based approaches for 3D USCT as opposed to full-wave inversion. First, full-wave inversion is still very computationally expensive. Second, full-wave inversion requires a low frequency component in the signal, which may not always be present, to avoid the 'cycle-skipping' local minima problem. Ray-based approaches can be used in their own right, or as a starting point for full-wave inversions (to overcome the cycle-skipping problem). But they suffer from some problems of their own. First, the time-of-flight must be accurately picked, which is a non-trivial problem due to the interference of scattered waves (especially when the bandwidth of the signal is limited). Second, straight ray approaches – which are computationally straightforward – do not give accurate images as the refractive effects are not accounted for. Using an iterative bent ray approach can ameliorate this latter problem, but introduces another problem of its own: ray-linking (tracing the rays from sources such that they hit detectors). Note that ray tracing approaches based on a calculation of wavefronts throughout the entire medium, e.g. Fast Marching Methods, are time consuming, and impractical for 3D geometries. We will present a volumetric USCT algorithm based on ray-tracing for estimating the 3D speed-of-sound map from measurements made on a hemispherical surface enclosing the breast. Algorithms to overcome the issues of time-of-flight picking and ray-linking will be described. We used an adaptive perturbation method for solving an associated ray link problem, the problem of calculation of the initial angle of the rays starting from an emitter so that the end point of the rays matches the receivers. Our developed ray-tracing approach gives much more accurate image than a ray-based approach using straight rays. The computational cost increases compared to using straight rays, but is still few orders of magnitude less than model-based approaches. As a result, a full 3D image reconstruction will be practical regarding the computational cost. Our next plan is to use some theoretical approaches for improving the spatial resolution and reducing the computational cost associated with the ray linking inverse problems.

(Invited) **Double bubble: The dual use of bubbles and droplets in medical diagnosis and therapy**

Brian Fowlkes

University of Michigan, USA

Stabilized microbubbles provide ultrasound contrast between vascular structures and other tissues is due to the high echogenicity of the bubbles and their nonlinear response. Superheated perfluorocarbon droplets can also be used to produce bubbles in situ by ultrasound in a process termed acoustic droplet vaporization (ADV). These droplets can be used as vascular agents, made sufficiently small for extravascular delivery in tumor tissue or formulated for implants used in tissue engineering. In each case, formulation can include encapsulate drugs for local release. Microbubbles can undergo stable and/or inertial cavitation resulting in physical effects to tissue such as enhanced heating or mechanical effects ranging from petechial haemorrhage to complete tissue emulsification, termed Histotripsy. This presentation will discuss the duality of microbubbles and droplet emulsions as diagnostic and therapeutic agents.

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Reverberant shear wave elastography in a preclinical mouse tumour model

John Civale, Jeffrey Bamber and Emma Harris

The Institute of Cancer Research, UK

Radiotherapy is one of the principal treatment modalities offered to cancer patients. A wide range of side effects and complications may arise during or following radiotherapy treatment. There is a clinical need to identify at an early stage during treatment those patients who may be at increased risk of developing complications, thus providing the opportunity to alter or seek alternative treatments for improved clinical outcomes.

Ultrasound imaging is an attractive modality for monitoring treatment response at tumour sites because of its properties: non-ionising, rapid, wide availability, and relatively inexpensive. Our group is interested in determining potential biomarkers which may be useful in detecting tissue response to radiotherapy. One of these biomarkers is tissue stiffness which may be estimated in relative or absolute terms by a variety of elastography techniques that have been reported in the literature and for which commercial implementations already exist.

Currently there is a lot of interest in imaging shear wave fields that may be generated by one or more sources, in such a way that generates for example a reverberant shear wave field1 from which the viscoelastic properties of the tissue may be estimated. Here we take this approach and consider its implementation in a preclinical mouse tumour model, with the aim of evaluating the imaging technique's potential, and secondly gaining an improved understanding of tumour response to radiotherapy treatment.

Here we report early progress made towards developing an ultrasound imaging system capable of imaging the induced shear wave fields in small (<1 cm) mouse tumours. A Verasonics Vantage system is used in conjunction with a L22-14vX high frequency probe (18 MHz centre frequency) to capture the shear wave field, in a way similar to the one reported by Ormachea et al2. Shear wave fields are generated in the tumour by means of a shaker coupled to the tumour, or other contact points on the mouse. Examples of the shear wave fields will be presented together with a discussion of some of the challenges in optimising the technique.

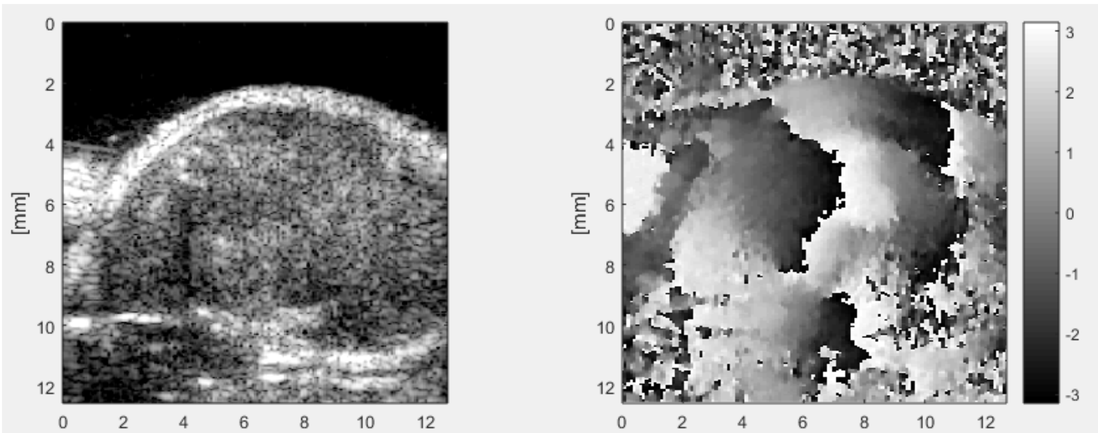

Figure 1: An example mouse tumour B-mode image (left), and associated shear wave phase map (rad) obtained using a 800 Hz vibration coupled to the tumour (right).

[1] Parker et al. Reverberant shear wave fields and estimation of tissue properties, PMB, 62, 1046-1061, 2017

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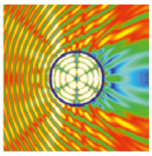

[2] Ormachea et al. Shearwave speed estimation using reverberant shearwave field: implementation and feasibility studies, UMB, 44, 963-977, 2018

Listening to oxygenation: Deep learning for estimating vascular sO2 with photoacoustic imaging

Ciaran Bench[1], Andreas Hauptmann[1,2], Simon Arridge[1], Paul Beard[1] and Ben Cox[1]

[1]University College London, UK [2]University of Oulu, Finland

Introduction

Unlike ultrasound, photoacoustic (PA) image contrast does not depend on the mechanical and elastic properties of the tissue, but instead, its optical absorptioni. As a consequence, PA imaging has the ability to detect haemoglobin and other light-absorbing chromophores. Thus, it is possible to acquire images of vascular blood oxygen saturation (sO2) from PA image data. However, an ill-posed non-linear inverse problem stands in the way of acquiring accurate estimates in vivoii. Techniques based on data-driven models, such as Deep Learning, have been used to extract quantitative information about chromophore saturation from simulated PA images of simple 2D tissue modelsiii. As we aim towards translating the technique to 3D in vivo images, a robust demonstration of the technique's ability to obtain accurate sO2 estimates in more realistic 3D tissue models consisting of multiple skin layers, and from images with limited-view reconstruction artefacts, is desired.

Method

As a first step towards implementing data-driven techniques for 3D in vivo imaging of sO2, we trained modified versions of the U-Net architecture both to estimate vascular sO2, and to segment the positions of vessels from simulated images. The networks were trained with 3D images of realistic tissue models, featuring noise and limited view reconstruction artefacts. The outputs of these two networks were used to estimate mean vessel sO2 in 40 tissue models.

Results and Conclusions

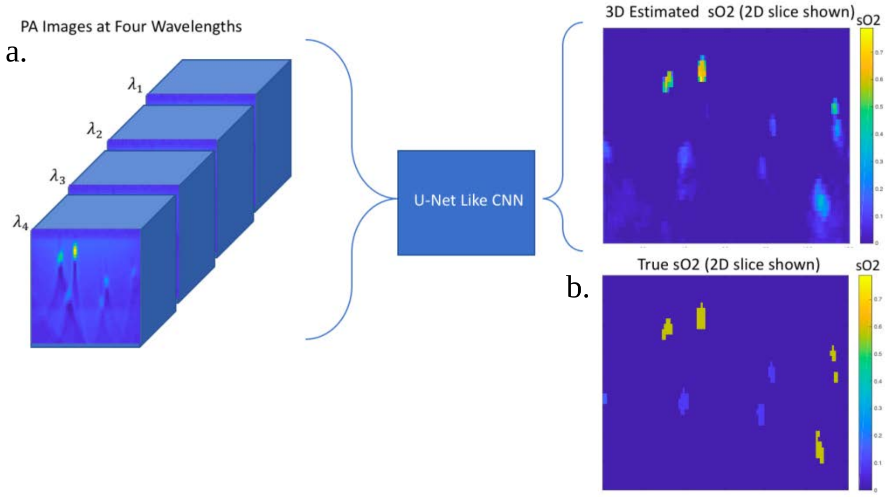

Figure 1: a. Schematic of the inputs and outputs of the sO2 estimating network. The output image shown is a 2D slice of the 3D output. b. The true sO2 distribution for this example.

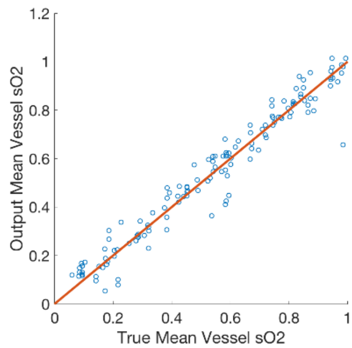

Figure 2: Output Mean sO2 vs True Mean sO2 for each vessel in 40 3D tissue models. The mean absolute offset in sO2 was 4.4% (calculated using segmentation and sO2 estimating network outputs).

This work demonstrates that data-driven techniques may be used to accurately estimate mean vascular sO2 from 3D simulated PA images of realistic tissue models, featuring some confounding effects which are likely to be present in images acquired from real tissues.

[1] Beard, Paul. Biomedical photoacoustic imaging". Interface focus 1.4 (2011): 602-631
[2] Cox, Benjamin T., et al. "Quantitative spectroscopic photoacoustic imaging: a review." Journal of biomedical optics 17.6 (2012): 061202.
[3] Gröhl, Janek, et al. "Estimation of blood oxygenation with learned spectral decoloring for quantitative photoacoustic imaging (LSD-qPAI)." arXiv preprint arXiv:1902.05839 (2019).

Characterization and technical validation of a multi-wavelength LED-based photoacoustic/ultrasound imaging system

James Joseph[1], Mithun Kuniyil Ajith Singh[2], Naoto Sato[3]and Sarah Elizabeth Bohndiek[1]

[1]University of Cambridge, UK, [2]Cyberdyne Inc, The Netherlands, [3]Cyberdyne Inc, Japan

Introduction
Photoacoustic imaging (PAI) has traditionally relied on slow, fragile and expensive lasers as excitation sources. Recent studies that report on the use of LED based PAI devices have demonstrated the potential utility of such systems in a range of biomedical applications [1, 2]. However, for LED based PAI systems to be adopted as a reliable diagnostic tool, the systems need to undergo a thorough technical and biological validation. Here, we report the characterization and technical validation of a LED-based PA/ultrasound imaging system that can perform real-time in vivo imaging.

Methods
A commercial LED-based PA and US imaging system was used in this study. We performed several systematic studies to evaluate the precision and reproducibility of the system. Measurements were made in stable tissue-mimicking phantoms to independently assess the impact of system variables. Temporal variation was assessed by repeated measurements over minutes, hours and days in the phantoms. In-vivo studies using small animals were performed to assess the in-vivo reproducibility of the system. Oxygen challenge PA studies were performed at 750nm and 850nm excitation (0.75 frames per second) with breathing gas modulated between medical air (21% oxygen) and pure oxygen (100% oxygen). For tracer uptake studies, the dynamics of intravenously

LED based PAI system for over 3 hours in phantoms was found to be excellent. The slope of the linear fit to the data acquired over 180 minutes indicates negligible system drift. Further, no significant system drift was observed during the course of 6 hour administered Indocyanine green (ICG) was assessed.

Results and Discussions
The temporal stability of the s. The impact of averaging on image signal-to-noise ratio (SNR) and contrast to-noise ratio (CNR) showed that frame averaging leads to enhancements in image SNR and CNR. Oxygen challenge PA studies that assessed the dynamics of SO2

PAI over time under multiple breathing cycles also gave corresponding changes in the measured SO_2^{PAI} levels (Fig 1a). Studies gave COV values of 3.55% for SO_2^{PAI} (Air) and 3.77% for SO_2^{PAI} (Oxygen) within same mice and 13.51% for SO_2^{PAI} (Air) and 13.68% for SO_2^{PAI} (Oxygen) across replicates. Dynamic contrast enhanced (DCE) imaging studies, clearly showed an increase in the signal from the baseline (Fig 1b).

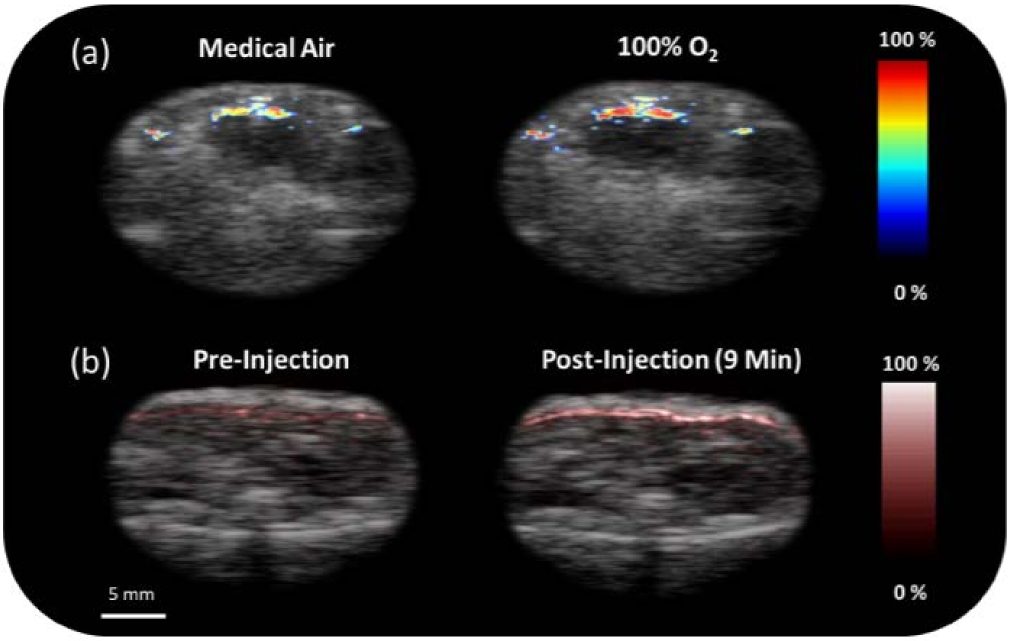

Figure 1: In vivo imaging using LED based PAI system. a) Blood oxygen saturation mapped under different breathing air cycles show clear variations in SO_2^{PAI} levels ; b) DCE studies using ICG clearly shows an increase in the PA signal from the baseline with an increase in the ICG concentration in liver.

Conclusions

Our studies show that the LED based PAI system offers excellent precision and reproducibility in phantoms and the system is capable of mapping blood oxygenation levels and uptake of exogenous contrast agents. Thus, high power light emitting diodes can serve as fast, robust and affordable excitation sources for PAI. LED based PA imaging is a promising tool for performing real-time functional and molecular imaging in preclinical research.

[1] Zhu, Y., et al., Light emitting diodes based photoacoustic imaging and potential clinical applications. Scientific reports, 2018. 8(1): p. 9885.

[2] Xia, W., et al., Handheld real-time LED-based photoacoustic and ultrasound imaging system for accurate visualization of clinical metal needles and superficial vasculature to guide minimally invasive procedures. Sensors, 2018. 18(5): p. 1394.

(Invited) **Characterizing spatiotemporal dynamics of fetal brain development from ultrasound images**

<u>Ana Namburete</u>

University of Oxford, UK

Ultrasound (US) imaging is one of the first steps in a continuum of pregnancy care. During the fetal period, the brain undergoes dramatic structural changes, which are informative of healthy maturation. The resolution of modern US machines enables us to observe and measure brain structures in fetuses from as early as 14 weeks. Capitalizing on recent breakthroughs in machine learning, my group develops bespoke methods to automatically align brain images and track spatiotemporal patterns of intra-uterine brain development. In this talk, I will summarise our work on the design of data-driven techniques to build the first US-based atlas of the fetal brain. We envision that this atlas will serve as a population reference against which individuals can be compared, and hence enable detection of developmental deviations in routine clinical care.

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Initial results from a sparse sampling approach for distributed acoustic sensing

Robert Ellwood, Alastair Godfrey and Chris Minto

OptaSense, UK

Distributed acoustic sensing (DAS) has developed as a key technology in monitoring long linear assets in a range of industries including pipeline, oil/gas extraction, transport networks and perimeter security. OptaSense is the world's largest provider of DAS solutions and is the class leader in many applications of DAS. OptaSense's systems are sensitive primarily to strain, giving ultimately a measurement of strain change. As such the system is sensitive to temperature, strain and acoustic signals, to encompass this the system is often more accurately described as a Distributed Rayleigh Sensor (DRS). Recently interest has risen in the use of DRS to monitor the structural health of subsea cables connecting off-shore windfarms to protect significant investment in this infrastructure. It is believed that changes in the off-shore environment occur gradually over the course of weeks to months in response to external environmental inputs and occasional 3rd party interference.

DRS provides a wealth of information on physical processes occurring over a long linear length. The most significant challenges of acquiring all this information is in managing the volume of data captured. A demonstration of this is that the simplest DRS units produce data typically of the order of 1TB a day and in the latest generation of systems this can rise to ~30TB per day. This makes storage of data from and monitoring changes that occur over the period of months or years impracticable and is the reason why there is no such published data. This paper investigates an approach to adapt the way the data is acquired and stored to allow the management and processing of it to be suitably streamlined to allow practical investigation, whilst not inherently biasing the process. The approach applied combines a range of traditional techniques, as well as a simplified sparse sampling scheme. The aim of the technique is to allow a year's worth of data to be held in an easily manageable format.

We demonstrate the acquisition and analysis of acoustic data over the period of a month with this technique. This allows us to demonstrate changes in signals over this time period that would have not been captured by simple temporal decimation that would have not been apparent over a much shorter period and is inherently wideband. This analysis demonstrates a range of periodic variation in signals related to variation in the environment over the period of weeks, including tide heights Figure 1(a) and local traffic conditions Figure1(b). This technique has the potential to benefit the collection of data on a range of applications where DAS is used to monitor processes evolving over a significant period time.

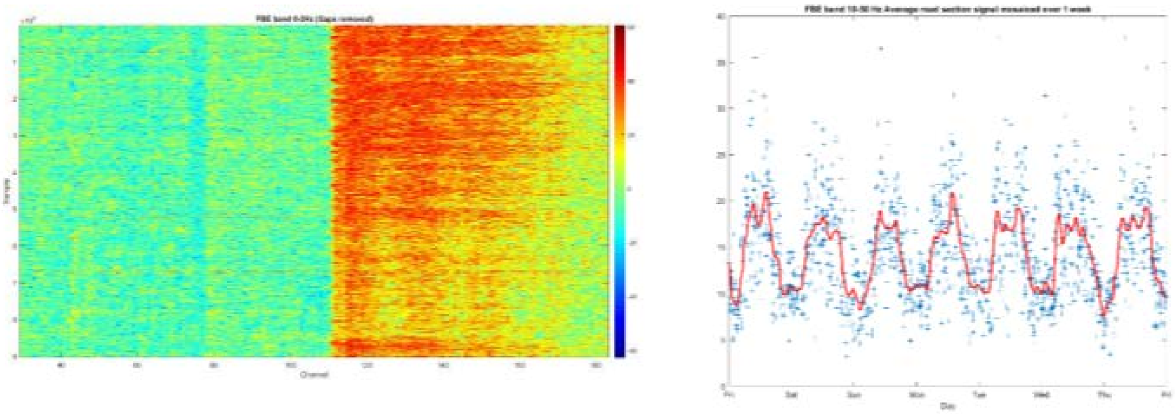

Figure 1: (a) image depicting the variation in tide heights over the period of the acquisition. (b) plot displaying average energy in road section over the period of a week

Monitoring sea ice with seismic noise

Ludovic Moreau, Pierre Boué, Agathe Serripierri, Jérôme Weis and Stéphane Garambois

Université Grenoble Alpes, France

Field data are needed for a better understanding of sea ice decline in the context of climate change. The rapid technological and methodological advances of the last decade have led to a reconsideration of seismic methods in this matter. In particular, passive seismology has filled an important gap by removing the need to use active sources. We present a seismic experiment where an array of 247 geophones was deployed on sea ice, in the Van Mijen fjord near Sveagruva (Svalbard). Stations recorded continuously the ambient seismic field in sea ice between 28 February and 26 March 2019. From the noise correlation function, the Green's function between the stations of the array is recovered and used to calculate the dispersion curves of the ice layer. These dispersion curves are then used in the inverse problem to infer sea ice thickness and mechanical properties.

Scattering of acoustic evanescent waves by spherical resonant objects

Ludovic Alhaitz, Diego Baresch, Thomas Brunet, Christophe Aristegui and Olivier Poncelet

Université de Bordeaux, France

Evanescent waves are particular solutions of the propagation equation. These waves are heterogenous plane waves which propagate along a given direction (generally the direction of an interface) with higher spatial frequency content than homogenous waves. According to the dispersion relation, they have an exponential decay of amplitude in an orthogonal direction. A well known application in optics or acoustics is the near field microscopy which consists in detecting evanescent components of the field to improve the image resolution. Such waves can be generated in a fluid or solid medium from a beam oriented beyond the critical angle of total internal reflection, by Bragg scattering through a periodic interface, or by modes conversions in waveguides. Here we consider the scattering of an incident evanescent field by a fluid or elastic sphere in order to expose the benefits of exploiting their special characteristics for innovative applications. To analyse the scattering of an incident evanescent plane wave, the field is decomposed in the spherical functions basis. Compared to the case of a homogeneous plane wave, additional scattered modes are excited and have a significant contribution in the resulting total field. For a given particle radius, Mie resonances occur at the same frequencies than for homogeneous plane waves, but with an altered amplitude in the wavenumber space that can be tuned by increasing the degree of evanescence of the incident wave. Due to the exponential decay of amplitude in the incident field, the scattered radiation was observed to present exotic structures, especially a rotating phase around the scatterer. These results could have important implications for the contactless manipulation of objects with acoustic radiation forces and torques, or for the remote detection of buried obstacles in the naval sector.

Frequency dependence of surface acoustic wave swimming

C Pouya, K Hoggard, S H Gossage, H R Peter, T Poole and G R Nash

University of Exeter, UK

In this work we study surface acoustic waves (SAWs) generated from a piezoelectric-transducer system and their behaviour within microfluidic systems. We exploit the leaky nature of SAWs which, when in contact with fluids, allow laminar jets to form. Recent studies investigated a range of SAW-fluid configurations ranging from bulk fluids [1, 2], droplets [3], and channels [4]. We investigate the effects of SAW frequency on laminar jets generated by SAW acoustic streaming in a SAW swimming system [5].

We report the first theoretical model of surface acoustic wave (SAW) swimming, exploring an overlooked fundamental property; the frequency dependence of the swimming force. We show an optimum frequency exists which generates a maximum force, which we confirm experimentally [5]. This improved understanding is vital to underpin future development of SAW swimming devices, comprising no moving parts, for applications including minimally invasive endoscopic surgery. Additionally, many swimming microorganisms have evolved propulsion methods to overcome drag using cyclic distortions of their body, mimicking the SAW swimming mechanism. SAW swimming could be used to obtain insight into the science underlying microorganism movement.

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(Invited) Elastic Metamaterials

Richard Craster

Imperial College London, UK

Elastic waves guided along surfaces dominate applications in geophysics, ultrasonic inspection, mechanical vibration, and surface acoustic wave devices; precise manipulation of surface Rayleigh waves and their coupling with polarized body waves presents a challenge that offers to unlock the flexibility in wave transport required for efficient energy harvesting and vibration mitigation devices.

In this talk I will describe various designs of elastic metasurfaces, based around a graded array of rod resonators attached to an elastic substrate that, together with critical insight from Umklapp scattering in phonon-electron systems, allow us to leverage the transfer of crystal momentum; we mode-convert Rayleigh surface waves into bulk waves that form tunable beams. Experiments, theory and simulation verify that these tailored Umklapp mechanisms play a key role in coupling surface Rayleigh waves to reversed bulk shear and compressional waves independently, thereby creating passive self-phased arrays allowing for tunable redirection and wave focusing within the bulk medium. We have also looked recently at piezoelectric coupling and the use of these devices in energy harvesting and, if time allows, I will discuss this too.

(Invited) **A two-dimensional Su-Schrieffer-Heeger acoustic network: observation of topological edge waves**

Vincent Pagneux

CNRS, LAUM, Le Mans Université, France

This talk is about the acoustic realization the two-dimensional (2D) Su-Schrieffer-Heeger (SSH) model in a simple network of acoustic ducts. The properties of the system is determined by using a set of discrete equations for the acoustic pressure at the nodes, leading to the 2D SSH Hamiltonian matrix without using the so-called « tight binding approximation ». By building an acoustic network operating in audible regime, the existence of topological band gap is experimentally demonstrated. Our results experimentally demonstrate topological edge waves in a zero Berry curvature system and also provide a simple platform for the study of topological properties of sound waves.

Metallic microparticles as key elements for the study of ultrasonic wave transport through strongly resonant scattering media

Fanambinana Delmotte, Gérald Clisson, Jacques Leng and Thomas Brunet

[1] Université de Bordeaux, France

Classical wave transport through strongly resonant scattering media has gained renewed interest in the field of wave physics. In that context, the study of dilute "resonant emulsions" [1] has revealed the impact of strong scattering resonances on ballistic and diffusive wave transport [2]. However, these all-fluid model systems made of disordered resonant fluorinated-oil (liquid) droplets have some drawbacks since these liquid scatterers might coalesce, especially when their concentration is too high.

In this talk, we present new ultrasonic pulsed experiments conducted on dilute suspensions made of disordered resonant metallic (solid) microparticles [3] that also exhibit strong shape resonances. All the key transport parameters are quantitatively investigated through accurate measurements of both ballistic and diffusive transport over a wide range of ultrasonic frequencies, such as the group and energy velocities. Finally, we discuss how these "resonant suspensions" might be ideal systems to evidence and to study Anderson localization of ultrasound in three dimensions, provided the microparticle concentration is high enough.

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Keywords: ultrasound, multiple scattering, suspensions, acoustic resonances, Anderson localization

Acoustic radiation torque in soft solids generated by vortex beams

Diego Baresch

Université de Bordeaux, France

The acoustic radiation force (ARF) has widely been investigated in fundamental research and clinical applications of ultrasound. In the context of tissue elastography, the ARF is used to locally push the medium by visco-elastic absorption of the incident momentum flux. Acoustic vortex beams[1], are special fields that additionally carry a flux of angular momentum useful for rotation[2]. In this presentation, we investigate the angular momentum transfer mechanisms in soft visco-elastic solids for potential use in applying remote torques. A vortex beam has a well-defined linear-to-angular momentum flux ratio that scales with the topological charge, a number describing the beam helicity. The value of this number is therefore important for the magnitude of the resulting torque. Transduction towards propagating shear waves in the solid will also be discussed. As for the ARF, we expect that the acoustic radiation torque will open opportunities to probe soft and biological matter and develop novel ultrasonic imaging strategies.

Keywords: Acoustic radiation force, Elastography, Radiation torque, soft solids.

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A model to predict the elastic field radiated by a magnetostrictive patch transducer into an omnidirectional waveguide

Guillaume Cousin[1], Alain Lhémery[1], Alexandre Impériale[1] and Sébastien Grondel[2]

[1]CEA-LIST, France Université Paris-Saclay, [2]UPHF, CNRS, Université de Lille, France

Magnetostrictive patch transducers (MPT) are commonly used in NDT, notably for pipe inspection by elastic guided waves. MPTs consist of a coil with or without a permanent magnet producing a dynamic electromagnetic field interacting with a static magnetic field in a magnetostrictive strip bonded to the part to be tested. Various magnetoelastic phenomena take place in the strip resulting in the generation of an elastodynamic field transmitted to the part. More precisely, an appropriate coil shape yields a wave-like stress-strain pattern, which allows efficient mode selection for guided wave (GW)-based methods in non-destructive evaluation. Of particular interest, this kind of transducer is able to generate high amplitude waves and tangential strain. Therefore, MPT constitute an interesting alternative to piezoelectric transducers in this context.

To ensure an optimal use for a given application, a proper design of the transducer is essential. Designing it makes necessary to consider all physical transduction phenomena, as well as the elastic radiation in the omnidirectional waveguide. For this purpose, we developed a simulation tool based on a semi-analytical modelling approach. Special attention is paid to electromagnetic source description, electromagnetic transductions in the patch, elastic coupling of the patch with the part, and elastic wave radiation in a guide.

The global model, which chains different sub-models is presented. The first sub-model predicts the electroacoustical transduction in the patch [1]. The second quantifies the elastic wave transmission from the patch surface to the part surface through the coupling medium, using Thomson-Haskell formalism [2]. It results in the prediction of surface stress distributions. These latter are the inputs of a third model for predicting GW modal radiation. GW field prediction can be post-processed to provide modal content and directivity of MPT.

As the first (resp. third) submodel has been validated by experiments [1] (resp. by FE computations [3]) we focus on validation of the second submodel by means of an in-house FE code [4]. Predictions by our second sub-model are in good agreement with FE results. Finally, configurations of interest for NDE are treated to illustrate some capabilities of the global model.

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Keywords: MPT – magnetostriction - GW -SHM - NDE - spectral finite elementUltrasound evaluation of bone fragility

In situ bubble dynamics controlled by an acoustical trap

Diego Baresch[1] and Valeria Garbin[2]

[1]CNRS, Université de Bordeaux, France, [2] TU Delft, The Netherlands

Micron-sized gas bubbles are notoriously difficult to isolate, handle and remotely control. Their large buoyancy in common liquids will usually force them to rise and burst at any gas/liquid interface or remain trapped against a solid boundary until dissolution. While bubble stability issues against dissolution have found numerous practical workarounds, the challenge remains at isolating and maneuvering a single bubble in free space to, for instance, characterize their dynamical response to applied ultrasound or to use them as active carriers for a specific payload deliverable on demand. Here we demonstrate that single-beam acoustical tweezers[1] can trap and manipulate in 3D a single bubble with the radiation pressure of helicoidal ultrasonic beams. Contrary to the situation where bubbles are trapped in the antinodes of a standing wave, the trapping vortex beam does not require oscillating volume changes of the bubble to generate a trapping force, *i.e*, the trapping mechanisms cannot be explained in terms of Bjerknes forces. We use the single-bubble trap to observe controlled bubble dynamics in presence of adjacent elastic boundaries and control the delivery of a payload to a targeted site.

Keywords: Acoustic force, manipulation, bubbles, radiation pressure, drug-delivery

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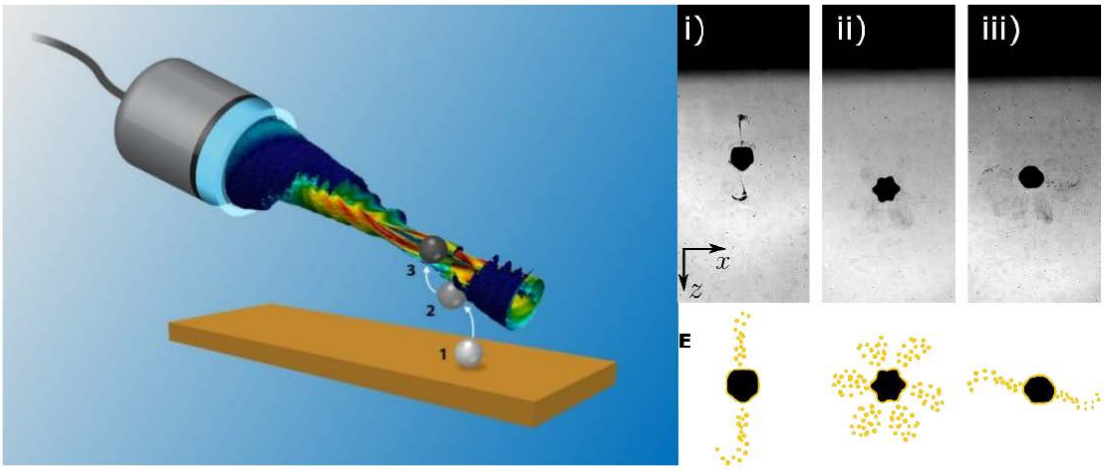


Figure 1: Controlling bubble dynamics with acoustical tweezers

Origin of the popping sound: a capillarity acoustic resonator

Mathis Poujol, Juliette Pierre, Arnaud Antkowiak, Regis Wunenburger and François Ollivier

CNRS, Institut d'Alembert, Sorbonne Université, France

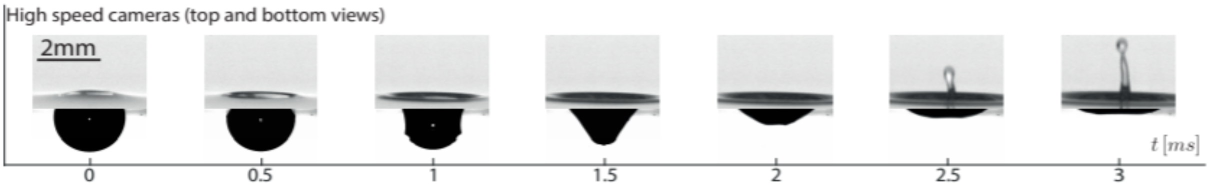


Fig. 1 : Sequence of images of the bursting of a 1mm radius bubble recorded using 2 high speed cameras : ones for the top view and the second to follow the submerged cavity

In this study we focus on the origin of the noise made by the bursting of a millimeter bubble floating at the surface of a liquid bath. Indeed, a capillary bubble bursts according complex interface reconfigurations (fig. 1) : the free film burst, capillary waves propagates at the liquid-gas interfaces and a fast thin liquid jet is ejected. What is the role of hydrodynamics in the air-borne and underwater acoustic emission ? Measurements were performed using one hydrophone, one microphone and two high speed cameras, all synchronised. With this experimental setup, we can correlate over time the liquid-gas interface reconfiguration and the acoustic radiation. In this presentation I will show you that a bubble bursting at a liquid interface acts like a Helmholtz resonator and that the film opening dynamic and the release of the initial Laplace over pressure drive the resonance effect.

(Invited) **The role of cavitation in therapeutic ultrasound**

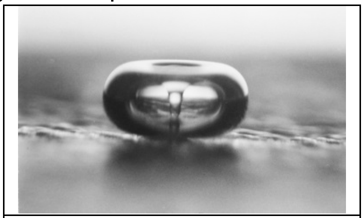
Lawrence Crum

University of Washington, USA

Therapeutic ultrasound has had a remarkable resurgence in interest within the medical community with the recent successful application of Focused Ultrasound to treat a number of clinical indications. Indeed, over 60 indications are under some form of clinical application, with the involvement of 40+ companies and over 250,000 patients treated.

In the overwhelming majority of these applications, the effect for which the therapy is induced is coagulative necrosis; i.e., tissue denaturation by elevated temperature. However, it is possible to induce tissue emulsification by acoustic cavitation, a method that has a number of useful advantages.

When cavitation is generated by an acoustic field, nucleation sites, containing microscopic amounts of free gas, can be greatly increased in size during the negative or rarefaction phase of the acoustic cycle. When the acoustic field become positive, this "cavity" is caused to collapse and in doing so, can create intense temperatures and pressures that can mechanically disrupt any medium in the vicinity of the collapse cavity. In particular, cavitation jets, shown in the accompanying figure can cause erosion of even the strongest materials.



Photograph of a collapsing jet within a cavitation bubble.

Methods to utilize cavitation to comminute kidney stones and to emulsify soft tissue have been developed in many different laboratories and are being incorporated into the clinical armamentarium.

This lecture will review the science of acoustic cavitation as well as describe several application of cavitation to therapeutic ultrasound.

Pressure-modulated shockwaves for inducing mechanical tissue destruction

Ki Joo Pahk

Korea Institute of Science and Technology (KIST), South Korea

High Intensity Focused Ultrasound (HIFU) is a non-invasive ultrasonic technique that has been traditionally used to thermally ablate solid tumours. HIFU can now be used to mechanically fractionate soft tissue with a high degree of precision of the order of millimetre size. This technique is known as boiling histotripsy. In boiling histotripsy, shockwave heating enables a boiling vapour bubble to be generated at the HIFU focus in soft tissue. Further interaction of incoming shockwaves with this bubble then leads to the generation of cavitation clouds which occur between the HIFU source and the primary boiling bubble. Because of this cavitation cluster formation, it is difficult to predict the size of a boiling histotripsy lesion as well as to control the degree of mechanical damage produced at a given boiling histotripsy exposure condition. To that end, in this study, a novel approach to eliminate or minimise the formation of cavitation clouds is proposed and demonstrated using a pressure-modulated shockwaves pulse. In this study, a 10 ms-long pressure-modulated HIFU pulse with a driving frequency of 2 MHz was used to create a boiling bubble and induce mechanical damage whilst minimising the shock scattering effects. A high speed camera and a passive cavitation detection system were used to observe bubble dynamics induced in liver tissue phantoms at the frame rate of 0.11 Mfps. Results show the formation and dynamic behaviour of a vapour bubble at the HIFU focus in the absence of the shock scattering effect-induced cavitation clouds. This boiling bubble eventually resulted in mechanical fractionation. This proposed method could be employed for precise tissue fractionation and cell therapy (e.g., tissue decellularisation).

OptimUS: an open source general purpose ultrasound simulation platform

Pierre Gélat[1], Seyyed Reza Haqshenas[1], Elwin van 't Wout[2], Samul Groth[3], Garth Wells[3], Timo Betcke[1] and Nader Saffari[1]

[1]University College London, UK, [2]Pontificia Universidad Católica de Chile, Chile, [3]University of Cambridge, UK

The clinical deployment of ultrasound therapies is hindered by challenges in treatment planning based on numerical models. For realistic clinical scenarios, simulation methods which employ volumetric meshes require several hours/days to run on a computer cluster. The wider clinical adoption and translation of therapeutic ultrasound will be greatly facilitated by the ability to produce fast and accurate patient specific simulations, with minimal computational overheads. For ultrasound scientists involved in preclinical research and for manufacturers of ultrasonic equipment, the ability to use open source software to rapidly visualise pressure fields in complex media bears significant advantages.

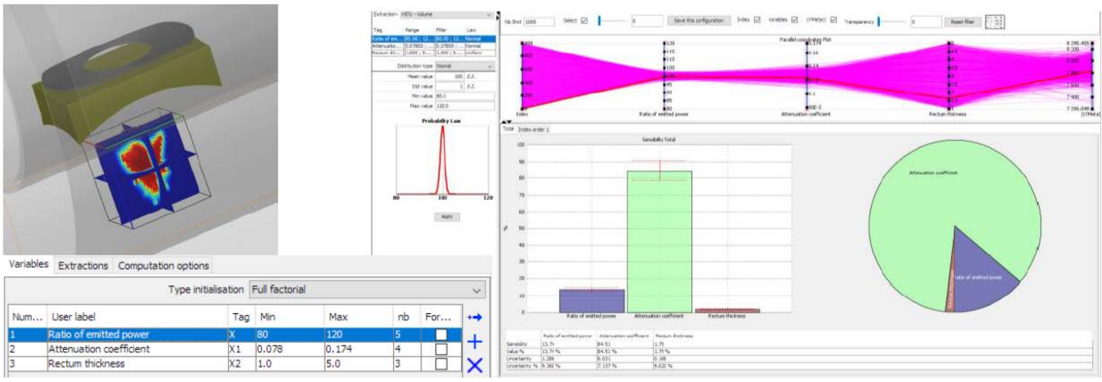
OptimUS is a general purpose open source ultrasound research platform featuring an easy-to-use Python front-end. The software employs a multi-domain boundary element modelling (BEM) formulation to calculate and visualise ultrasonic fields in complex media. Effects of nonlinear propagation are evaluated by coupling the BEM domain with a frequency domain finite element formulation which sequentially solves an inhomogeneous Helmholtz equation for each harmonic above the fundamental. The BEM formulation employs efficient preconditioners and matrix compression techniques, enabling the interactions of incident ultrasonic fields with multiple tissue domains to be computed. This can be achieved within a realistic clinical timeframe, and with no staircasing and minimal numerical dispersion effects. Constrained optimisation techniques provide the possibility to focus through scatterers such as bone and to reduce scattering at boundaries where there is significant contrast in tissue properties. OptimUS also provides a simple framework for modelling ultrasonic sources such as planar, bowl and array transducers. Convergence tests demonstrate that meshes involving four elements per wavelength produce results within 5% of the analytical solution to the problem of a sphere impinged by a plane wave. Calculations on anatomical meshes show that the presence of tissue heterogeneities and strong scatterers such as bone can lead to substantial aberration of the focus, lensing effects and a reduction in peak pressures.

Applications of intensive HIFU simulation based on surrogate models using the CIVA healthcare platform

Sylvain Chatillon[1], Raphaël Loyet[2], Laurie Brunel[3], Françoise Chavrier[2], Nicolas Guillen[3] and Stéphane Le Berre[1]

[1]CEA, LIST Université Paris-Saclay, France, [2]Université Lyon, France, [3]EDAP-TMS, France

For several years, CEA-LIST has been developing in partnership with INSERM, a HIFU simulation platform, CIVA Healthcare. It provides specific tools for the development and optimization of probes and therapeutic protocols in order to target clinical problematic of specific organs. The goal of this platform is to easily simulate the 3D pressure field induced by HIFU, in linear regime, and the corresponding thermal dose in tissues and phantoms. Parametric studies for treatment optimization (probe design, protocol definition, etc...), sensitivity analysis, and tissue characterization using parametric inversion can be easily performed. A common feature of these studies is the need for a large amount of input data, which involves many simulations. This often makes these problems too expensive to deal with by standard numerical simulation approaches. In such contexts, it is often convenient to replace the computationally expensive direct solver with a surrogate model built from a database of simulation results, and acting as a quick and accurate surrogate restricted range of input parameters. This procedure breaks down into two stages. In a first step (off-line part), the database is adaptively constructed to maximize the fidelity of the associated interpolator computed from the pairs (I / O) of the database. In a second step, also known as the off line part, the interpolator, also called surrogate model, enables to generate signals in near real time for configurations covered by the range of the database.



Sensitivity analysis of HIFU lesion using simulation

Two applications based on the generation of surrogate models will be proposed. The first one concerns real-time pressure field computation. The second one, based on thermal simulations, deals with sensitivity analyses according to the uncertainties of the tissues parameters.

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IOP Institute of Physics

Anglo-French Physical Acoustics 2020

15–17 January 2020, Selsdon Park Hotel, Surrey, UK

Fetal acoustics: a computational study

Seyyed Reza Haqshenas[1], Ganesh C Diwan[1], Elwin van't Wout[4] , Julian Henriques[2], Eric Jauniaux[1], Aude Thibaut[3], and Pierre Gélat[1]

[1]University College London, UK , [2]Goldsmiths, University of London, UK , [3]Sonic Womb Productions Limited, UK , [4]Pontificia Universidad Católica de Chile, Chile

Exposure to noise for pregnant women is a fact of modern day living. In a recent study, one quarter of employed women aged 30 to 49 reported occupational noise exposure during at least one quarter of the day, so loud that they could not have a normal conversation. This can affect women working in factories and in construction, and professional musicians. Pregnant women may also be subjected to other noise sources, associated with modern living, such as the London Underground, loud music and also MRI scans, where peak sound pressure levels have been reported to exceed 110 dB(A).

There is evidence that the fetus can respond to sound stimulus from 24 weeks of gestation. Adverse effects of noise exposure on the fetus reported in the literature include association with hearing loss, reduced birth weight, congenital malformations, risk of premature birth and preeclampsia. Mechanisms proposed for these effects include maternal stress, sleep disturbance and increase in blood pressure. High-frequency hearing impairment in babies of mothers exposed to high levels of occupational noise during pregnancy has been considered to be a consequence of a mother's stress induced by exposure to noise.

The actual mechanisms of physiological damage from noise have yet to be fully understood although research has demonstrated that a multitude of factors, including increased oxidative stress, vascular changes, and mechanical trauma may be responsible. To date, the role that mechanical stresses may play in adverse effects of noise exposure on the fetus has rarely been discussed. Nevertheless, sound, being a mechanical wave, has the ability to damage tissue.

In addition to studies on large cohorts and on animal models, in order to establish the adverse effects of noise exposure on the developing fetus, validated computational models using anatomical data have a key role to play in understanding the complex physics of wave propagation inside the body. The computational domain is in this case heterogeneous, comprising different tissue types with varying physical properties (i.e. density, sound speed and absorption) leading to multiple scattering effects and attenuation of sound waves. There are numerous approaches available for solving 3D full wave equations in heterogeneous media. In the present study we investigate the application of the finite element method (FEM) for computing the in utero acoustic field using anatomical meshes obtained from MR scans. At high ka values, where k is the wavenumber and a is the characteristic length, and where there is a high contrast in material properties (e.g. at air/soft tissue interfaces), preserving accuracy of the model requires highly refined meshes necessitating high performance computing platforms and methods. We review the use of FEM direct and iterative methods for solving this problem. In addition, we review the state of-the-art multiple domain nested boundary element methods (BEM) and their application for solving this problem. In BEM only the boundaries of the domains (abdomen, uterine, fetus) require discretisation, which makes BEM suitable for solving large scale propagation problems. Using an anatomical mesh based on an MR scan of a pregnant woman, we find that computational results support the hypothesis of resonant behaviour inside the uterus as reported in the literature on experiments in sheep models.

Keywords: Finite element method, Multiple domain nested boundary element method, Helmholtz transmission problem, fetal acoustics.

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Design and construction of a low-frequency ultrasound system for brain imaging

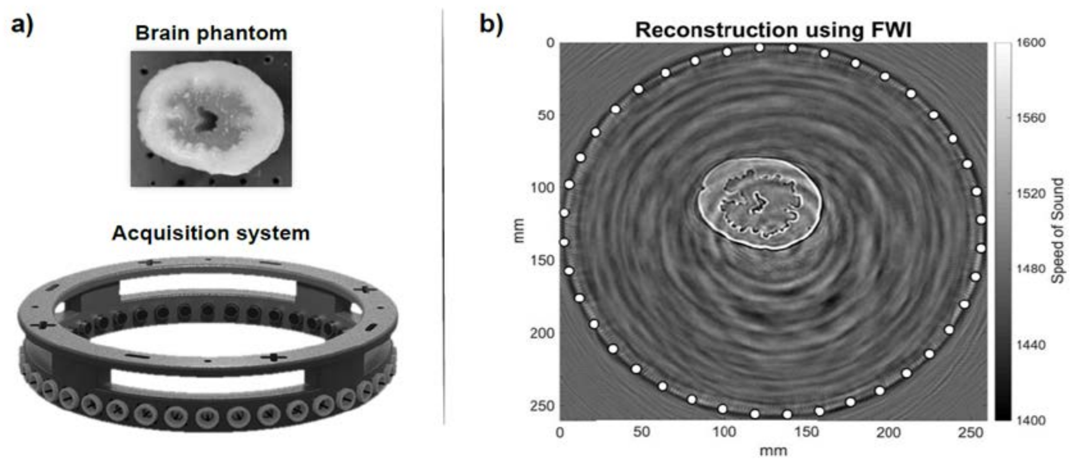
Javier Cudeiro, Carlos Cueto, Tom Robins, Oscar Bates, George Stronge, Oscar Calderon, Lluis Guasch, Mengxing Tang and Mike Warner

Imperial College London, UK

Conventional ultrasound methods cannot image the human brain because of the highly reflective nature of the skull and its complex structure. Ultrasound beams get reflected, diffracted and trapped inside of the head, making existing techniques incapable of producing coherent images of intracranial soft tissues. The main reason why these methods fail is because they rely on reflections produced by soft tissues to form an image. In this case, such reflections get obfuscated by much stronger waves that appear due to the geometry of the skull. However, low-frequency ultrasound gets less attenuated than higher frequencies, and can transmit stronger signals through the skull. This offers the possibility of forming an image by using transmission in addition to just reflections. The challenge is that it can only provide low-resolution images when conventional medical imaging techniques are used.

We propose the implementation of an existing algorithm developed for exploration seismology: full-waveform inversion (FWI), together with a custom-made low-frequency acquisition system to overcome these limitations and achieve high-quality images of the brain. FWI utilises the phase and amplitude information of the signals received at each location to measure a mismatch between recorded and numerically-simulated data and iteratively refines the model until this data mismatch is minimised.

We have already demonstrated the feasibility of FWI in ultrasound medical imaging by reconstructing an in-vivo breast dataset (ref1). Here, we present the first results of our laboratory experiments using our 2D acquisition system design: a rotating ring of 40 low frequency ultrasound transducers. In the centre of the ring we place a tissue-mimicking phantom of the brain and skull. Although this phantom is technically a 3D volume, it has the same 2D geometrical pattern along its third axis to prevent off-plane energy from being present in our acquired data. The attached figure shows a) the brain phantom, our target, and the acquisition system, and b) the reconstructed image of such target using FWI. This is the first step towards a genuine 3D solution which will consist of a full hemispherical array capable of imaging complex three-dimensional targets.



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Full waveform inversion for ultrasound tomography of the brain: An uncertain approach to finding the correct starting parameters

Oscar Bates, Lluis Guasch and Mengxing Tang

Imperial College London, UK

Research regarding ultrasound imaging of the human brain is limited, despite clear clinical benefits. Attempts have been made using 2D tomographic approaches with time-of-flight (TOF) tomography [1] or diffraction tomography [2]. The fundamental problem with these reconstructions is the high impedance contrast of the skull.

Full waveform inversion (FWI) is a reconstruction algorithm which may be able to image intracranial soft tissue through an intact human skull. In Geophysics FWI is used to build high resolution quantitative reconstructions of sub-surface properties [3], typically acoustic sound speed. Figure 1 shows a schematic diagram of the FWI algorithm. The key advantage of FWI is that it performs a numerical simulation of the wavefield propagation with the correct physics. In other words, FWI doesn't invoke the Born approximation in the forward problem. This means FWI is capable of accounting for high contrast features in the reconstruction space, unlike TOF or diffraction tomography.

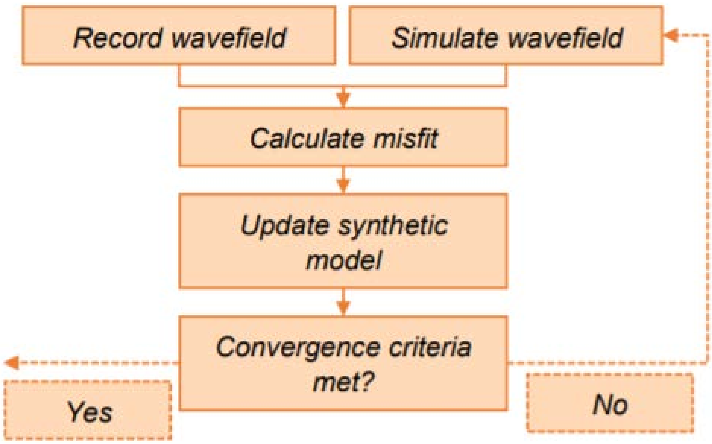

Fig 1. A simplified description of FWI, full details can be found in [3]

FWI is limited by its significant computational cost and the presence of local minima in the solution space. The most problematic is "cycle-skipping", which occurs when the arrival times of the recorded and simulated wavefields are more than 180° out-of-phase [3]. The simplest solution is an accurate estimate of the starting parameters. In-silico FWI reconstructions of the head are shown when starting from a point estimate of water. However minor changes to the bandwidth of the simulated transducers or the thickness of the skull can reintroduce cycle-skipping. To fully solve the problem of cycle-skipping a more detailed prior is necessary. A generative model could be used to find the correct subject-specific starting parameters. Thus, we estimate the starting parameters from a distribution rather than making a point estimate. The starting parameter model should incorporate the acoustic and geometric properties of the human head. Research in Focussed Ultrasound suggests this model should be x-ray CT based because of the direct correspondence between absorption (HU), density (g m^{-3}) and sound speed (m s^{-1}) [4]. Therefore, the geometry of the head will be encoded in the x-ray CT (HU) domain before being translated into the acoustic (g m^{-3}, m s^{-1}) domain.

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Multi-band finite element simulation of ultrasound absorption by soft tissue

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Knowledge of the attenuation of ultrasound through human soft tissue may be used as a tool for the diagnosis of disease such as cancer, either directly (where the attenuation of the tissue plays the role of a diagnostic metric [1]), or in a secondary sense (where the attenuation is used in calculation of the ultrasound backscatter coefficient of deep tissues [2]). In the latter case, accurate estimation of the ultrasound attenuation in vivo could provide clinicians a more reliable method of evaluating the scattering properties of tissue in vivo. In this context, the methods used to calculate attenuation are impractical, so a simulation approach is proposed. To apply this attenuation compensation in the case of absorption-based losses, a multi band finite element method [3] is proposed, where frequency dependent attenuation effects are modelled without the need to directly model the viscoelastic behaviour of tissue components. This approach benefits from flexibility in modelling arbitrary frequency dependent behaviour without the associated penalty in computation time. Results presented will be based on materials mimicking soft tissue to highlight potential medical applications of the approach.

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Measurement of the temperature-dependent output of a PZT transducer

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Background, Motivation and Objectives

The effect of temperature on the output of PZT transducers has not been widely studied in the literature. The problem is of particular interest in non-destructive testing and temperature sensitive applications such as thermometry. Here, we investigate the temperature-dependent pressure output of a 2.25 MHz unfocused PZT transducer from Olympus (Panametrics NDT, Tokyo, Japan) between 22 °C and 48 °C.

Methods

The temperature-dependent output of the PZT transducer was investigated using both radiation force measurements and laser Doppler vibrometry. The electrical input to the transducer was also assessed as a function of temperature in order to determine the transducer's efficiency at elevated temperatures. Radiation force balance (RFB) measurements were performed at the National Physical Laboratory. Two configurations were chosen utilising (1) a suspended flat absorbing target made of HAM A acoustic absorber material and the NPL Secondary Standard balance (CC1200 Comparator, Sartorius, Göttingen, Germany), and (2) suspended air-backed convex cone used as a reflective target and the NPL Reference Therapy Level balance (AC211S Balance, Sartorius, Göttingen, Germany). The laser Doppler vibrometer (Polytec OFV-5000 vibrometer and OFV-505 laser, Waldbronn, Germany) was coupled with a displacement decoder (Polytec DD-300, Waldbronn, Germany) with a scaling factor of 25 nm/V. The vibrometer measured the displacement of a thin reflective pellicle (placed on the water surface) which passively moved with the ultrasound pulses emitted by the PZT transducer.

Results, Discussion and Conclusions

The change in the transducer's total radiated power output over the temperature range from 22 °C to 48 °C from both RFB configurations exhibited an increasing trend with temperature corresponding to approximately 38% increase from 22 °C to 48 °C. The electrical power in the same temperature range increased by 28%. The efficiency of the transducer was then calculated as the ratio of the radiated power to electrical power, and was shown to increase by 11% from 22 °C to 48 °C. When converted to pressure, these results indicate an increase in pressure amplitude of 18%. The temperature-dependency of the pressure output of the PZT transducer as characterized using laser Doppler vibrometry depended on the drive conditions. Under pulsed wave conditions, the transducer output was fairly constant, while using toneburst an increase in the generated pressure of approximately 15% was observed. Using two independent methods, we have shown that the output of a PZT transducer increases with temperature over the range from 22 °C to 48 °C.

Local evaluation of elastic *moduli* by ultrasounds. Towards the mapping of mechanical properties of adhesively-bonded joints

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The use of bonded joints is limited because of the lack of non-destructive methods to check the quality or strength of bonds. However, it has been shown that some defects located at the substrate/adhesive interface, sparsely echogenic, can be detected via ultrasonic measurements of adhesive elastic *moduli* [1]. The used characterization method is based on the resolution of an inverse problem that minimizes the difference between measured ultrasonic transmission coefficients (for an immersed assembly and using large transducers) and those calculated under a plane wave assumption.

The current work proposes a method allowing the evaluation of the bonded joints' mechanical properties at a more local scale using small or focused transducers. Numerical methods developed under plane-wave assumption have then to be extended to bounded or focused beams. The first step is to implement the direct problem in two dimensions, i.e. to calculate transfer functions for several incident angles (spectrum *moduli* of ultrasonic fields transmitted by an immersed plate and divided by that without plate).

Firstly, a comparison between plane-wave and bounded-beam models is done in a case where the plane-wave assumption is assumed to be valid (i.e. the emitter is much larger than the wavelength in water [2]). In the case of an ultrasonic beam at normal incidence through an isotropic plate, differences between both types of predictions are observed. Indeed, with the bounded-beam model minima are observed in the transfer function, which are not predicted by the plane-wave model. Thus, the criterion commonly used in literature to justify the plane-wave assumption is not sufficient. However, these differences provide another information: those minima are located at transverse cut-off frequencies of some backward Lamb waves and are linked to the celerity of the shear bulk wave, c_s, by $f_m = mc_s/2d$ where d is the thickness of the plate and m=1,2,3… At normal incidence, the plane-wave model considers only longitudinal waves propagating through the immersed solid. This model allows the measurement of C_{11} only, where 1 is the direction normal to the plate. With the finite beam model the shear bulk wave is also taken into account and thereby could lead to evaluation of C_{66} (shear modulus) either by inverse problem resolution or by minima measurements. This phenomenon is more pronounced using small or focused beams, which may also generate Zero Group Velocity (ZGV) modes appearing as maxima on the transfer function.

The application to adhesively-bonded assemblies is in progress and the contribution of the bounded-beam model is investigated to assess elastic *moduli* of adhesives. This model should allow mechanical properties to be locally evaluated, so that mapping of adhesive properties might be possible, revealing bonds strength and weakness spatial distributions.

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A semi-analytical finite element method for the forced response and surface wave propagation in multilayered solid spheres

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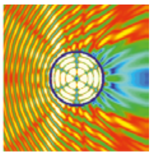
The computation of the eigenmodes of solid spheres is a classical problem in mechanics solved more than a century ago by Lamb. This topic has found many applications in geophysics, composites structures and non-destructive testing. The eigenmodes are the solutions of a dispersion relationship which can be obtained analytically. However, numerical methods are preferred for complex structures such as multilayered spheres. One dimensional models can be obtained based on semi-analytical methods, in which the angular directions are described analytically (based on spherical harmonics functions) and the radial direction is discretized. This approach yields a linear eigenproblem which is simple to solve.

The existing semi-analytical methods (Heyliger & Jilani, 1992 ; Park, 2002) are not fully satisfactory. Indeed, the related eigenproblems are not given in a closed-form (numerous integrations are required) or are specific to a choice of interpolating functions. We propose a more general formulation. The main issue is to correctly identify the orthogonality relationships of spherical harmonics, used to uncouple the angular and the radial directions. Because the elastodynamics equations are vector wave equations, both vector and tensor spherical harmonics orthogonalities are required. While the orthogonality of vector spherical harmonics is rather well-known and straightforward, the orthogonality of tensor spherical harmonics is much more mathematically involved (Martinec, 2000). In this work, a closedform eigenproblem is eventually obtained for any interpolating function and favourably compared to literature results (Eringen & Şuhubi, 1975).

Additionally, the forced response can be calculated explicitly based on the eigenmodes. It can be used to reconstruct surface wave propagation phenomena. We particularly focus on the phenomenon of Rayleigh wave collimation described by Clorennec and Royer (2004): for a line source of specific width, the Rayleigh wave is not diffracted on the surface of the sphere but propagates with a quasi-constant width. We show that this phenomenon is accurately recovered with our numerical model. An analysis based on eigenmodes is proposed. We also study the perturbation induced by the addition of a thin viscoelastic coating.

Furthermore, the case of an infinite embedding medium surrounding the sphere is also considered. In that case, the radial direction must be bounded so that the problem can be numerically handled. For that purpose, a radial Perfecty Matched Layer (PML) of finite thickness is applied. The leakage amount (radiative losses) of eigenmodes, of practical interest to select the modes with the highest quality factor, is then evaluated. The existence of a collimating wave with an infinite surrounding medium is also investigated.



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Quantitative ultrasound imaging under anisotropic conditions: application and perspectives for wood evaluation

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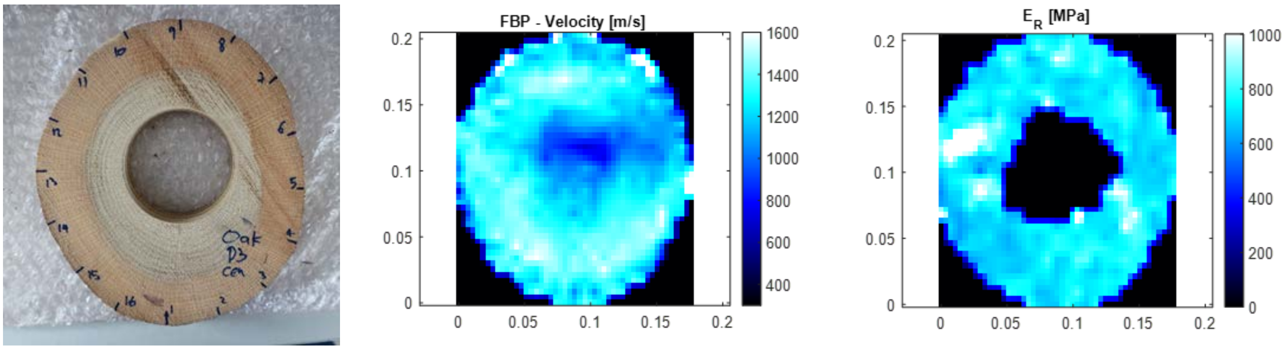
In order to manage urban trees in modern cities, operators need tools to evaluate their phytosanitary state [1]. Among the different evaluation protocols, acoustic and ultrasound non-destructive imaging methods have been recently used to analyze the inner structures of trees without altering their condition [2]. Here we are concerned about evaluating the influence of the anisotropic condition in wood on the tomography image reconstruction using ultrasonic waves, and more precisely, how the tomography image reconstruction process (inverse problem) should be adapted to the standing tree constraints. The aim of this study is to present strategies for the solution of the inverse problem in anisotropic media such as wood (and therefore adapt it to other analogous materials, such as bone for example). Considering ultrasonic time-of-flight tomography, ray paths are not known a priori, then the solution to the inverse problem requires an optimization procedure to adapt iteratively the trajectories, via a raytracing model, to minimize a function of the time-of-flight and the trajectories. Then, for each pixel in each trajectory, the corresponding slowness value can be used to calculate the inner wood mechanical parameters, using the Christoffel equation. Compared to the images obtained using the hypothesis of isotropic condition, the proposed method resulted in a more accurate defect identification, adapting the curved rays to the defect presence and delivering a parametric image more suitable for the diagnostic process (Fig. 1). In the longer term, the idea of considering all the physical phenomena involved could make it possible to achieve a much better characterization of the wood material. A potential method to address this strategy is the Full Waveform Imaging (FWI) method [3].



(a) (b) (c)

Figure 1: (a) Oak sample with a centered defect, (b) FBP reconstruction (isotropic assumption) (c) parametric image with the proposed method (anisotropic assumption)

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Guided Wave NDT: the contributions of numerical prediction and computed tomography

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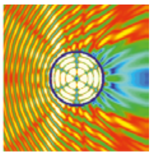
Elastic guided waves (EGW) based methods are increasingly being used for non-destructive testing of large structures, such as storage tanks and pipelines. Understanding wave propagation in such complex media is challenging. In the current work carried out at the LMA, spectral element based numerical predictions of propagation in a storage tank were performed. Based on the purpose of [1], we proposed an improved methodology which led to: the analysis of the complex-multimodal propagation, the assessment of the transmissibility of information through the tank bottom, and the prediction of the global diffusive effect due to lap joints, see fig1. The quantitative modelling approach we selected in this methodology is based on the isotropic plate-membrane approximation. This has contributed to the analytical description of EGW phenomena: S-A-SH mode conversion, scattering by thickness losses, and delay due to dispersive modes. The validity of this approach, as well as the thickness reconstruction issues were discussed [2]. Experiments were carried out on small-scale, 2 mm thick, steel plate samples, at 250 and 500 kHz. The two main objectives were: to measure the transfer function of T-joint and lap joint in the fundamental range, and to study the performance of computed inverse scattering of calibrated defects, see fig2. The presented results lead to conclusions about defect detection, instrumentation issues, and relevancy of guided wave tomography.



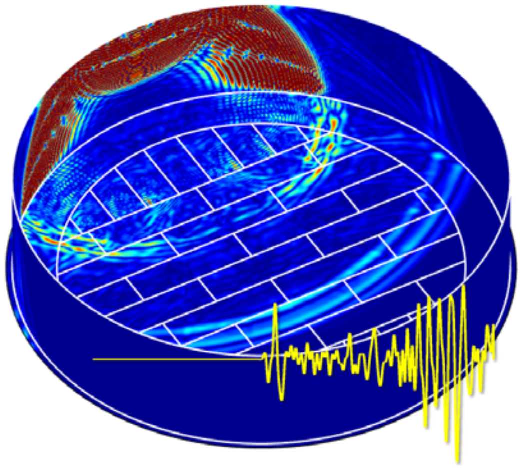
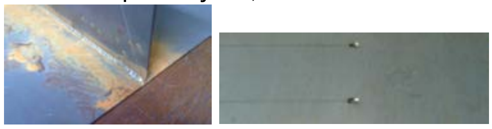
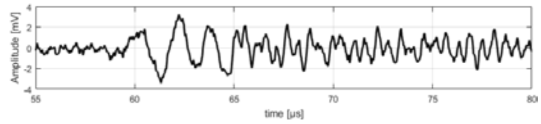


Figure 1: Numerical prediction of EGW propagation in a 4 m diameter storage tank, transient response to a 50 kHz pulse

(a) Tested samples: T-joint, thickness loss defects



(b) Example of measured echo from a defect



(c) Computed reconstructions for different defect depths

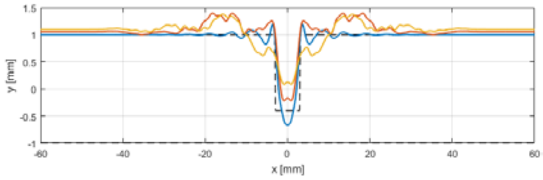


Figure 2: Guided waves experiments

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Keywords: guided wave tomography – corrosion – non-destructive testing

Low power EMATs, coded excitation and measurement of SNR during probe motion

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This paper will report on research progress in relation to coded excitation of ultrasonic signals and, in particular, their application to acquire data from EMATs that are in motion. Coded excitation improves signal to noise ratio (SNR) of the acquired signals and it can be employed to build low power EMATs. A sequence of pulses is sent to increase the energy that is inserted into the medium. At the receiver the signals are pulse compressed so that a temporally short output with high SNR results. The author and co-worker have explored the use of very long codes to yield a large SNR improvement. For long codes the transmission time can reach several milli-seconds which raises the question of the effect of probe or specimen motion on the overall SNR of the acquisition. In this work the effect of motion on the acquisition process with long coded excitations is investigated. A simple simulation model to predict the performance will be presented and experimental validation measurements that confirm the model predictions for a thickness measurement setup will be shown. For reasonably uniform reflectors (a structure of slowly varying thickness) it is shown that speeds of 1m/s can be used if moderate SNR drops of 6dB can be tolerated.

Surface wave methods to monitor fatigue degradation in steel components

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The ability to characterize the fatigue state of engineering components is crucial, particularly for those used in safety-critical applications, such as the components in pressure-containing power plants. These parts are subjected to cyclic pressure and temperature, which induce fatigue damage on their surface. Presently, the industry uses very conservative fatigue life estimations, resulting in an overall increased cost in inspecting and maintaining them. Hence, this poses the need for developing a method to characterize accurately their fatigue state, in an industrial environment.

Fatigue damage will alter a material's microstructure. Research has shown that ultrasound will react to microstructural changes, with both its amplitude and velocity changing with respect to their initial values [1]. This result has been experimentally verified with conventional UT, however the changes observed were too small to be considered reliable in an industrial application [2,3].

Bulk wave measurements on samples with deliberate fatigue have successfully identified fatigue zones, through a change in the wave's amplitude and propagation speed. Those changes are, however, small and, given that fatigue is primarily a surface phenomenon, it is hoped that improved sensitivity can be achieved by conducting the measurements using surface waves. Results from finite element studies have shown their use to be promising, with the changes being larger and easier to observe, while experimental studies are in progress.

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(Invited) **Ultrasound evaluation of bone fragility**

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Ultrasound echoes from the inside of a bone can be processed with dedicated reconstruction algorithms to obtain a quantitative image of the cortical bone layer. This provides a measure of bone thickness and apparent material properties. Typically, longitudinal and shear wave velocities in different anatomical directions can be measured (bone is anisotropic). During the last 10 years, we have studied the inter-individual variations of bone elastic properties, and their meaning in terms of material composition and microstructure, and strength. This provides a basis for the definition of biomarkers of fragility from ultrasound measurements. In the course of our research, we adapted the Resonant Ultrasound Spectroscopy (RUS) technique to measure the anisotropic stiffness tensor of small bone specimens and other materials with low Q-factors. In the talk, we will present the state of the art ultrasound techniques to assess bone in vivo and ex vivo. We will give a summary of our research on the measurement and multi-scale modelling of bone elastic properties. Finally, we will discuss the technical challenges to be addressed in the emerging field of research of intra-osseous ultrasound imaging.

Optimised data acquisition for laser induced phased arrays

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Laser induced phased arrays (LIPAs) have been shown to achieve comparable image quality to that of conventional laser ultrasonic techniques in the non-destructive regime[1]. This was achieved by adopting the Full Matrix Capture data acquisition method, capturing signals from every transmit-receive element combinations of the array, then processing the data using the Total Focusing Method, focusing on every pixel of a pre-defined grid, in post-processing. LIPAs provide a couplent-free, wideband, remote ultrasonic imaging technique for places of restricted access, in extreme environments and on complex surfaces. However, LIPA synthetisation using one laser for generation and for detection requires long scanning times, thus greatly decreasing capabilities in applications where timing is a key factor, for instance in the case of in-process inspection.

Unlike conventional transducer based phased arrays, LIPAs can be reconfigured thus they can be optimised for specific experiments. In this work a technique is proposed in order to overcome the long scanning times required for synthesising LIPAs by optimising array characteristics including pitch, number of elements, element location and array aperture. In this two-stage data acquisition method, initially, potential defect locations are rapidly identified. Following this, the optimised scan is performed taking into consideration defect location, laser ultrasound's directivity pattern and the sensitivity pattern of the detector.

The technique was performed on a previously captured Full Matrix data set. The resulting image with higher quality near defects and lower quality where nothing is present, showed that the total scanning time was reduced ~10 times compared to conventional FMC and TFM imaging without compromising the Signal-to-Noise Ratio of defects.

Keywords: Laser Ultrasonics, Phased Arrays, Total Focusing Method, Remote Ultrasound, Non-Contact, Ultrasonic Imaging.

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Laser-ultrasonics-based inspection of cracked or adhesively-bonded plates with zerogroup-velocity (ZGV) Lamb modes: imaging and characterization

Romain Hodé[1,2], Haiyang Li[1] , Juliette Alcaraz[1], Nikolay Chigarev[1], James Blondeau[1], Nicolas Cuvillier[2], Mathieu Ducousso[2], Vincent Tournat[1], Vitalyi Gusev[1] and Samuel Raetz[1]

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Laser monitoring of zero-group-velocity (ZGV) Lamb modes excited by laser is a contactless non-destructive evaluation method, which has been extensively investigated since 2005 [1]. A ZGV Lamb mode is a specific solution of the Rayleigh-Lamb wave equations in a plate for which the group velocity vanishes while the phase velocity remains finite. The acoustic energy of this mode cannot propagate in the medium, which gives rise to a sharp local resonance and makes of the ZGV modes good candidates for local probing of a material. Where a plate is cracked through its thickness or where a plate is bonded to another one, the boundary conditions at the crack edge or at the initially-free surface are changed, which influences the ZGV modes. In the vicinity of a free plate edge, ZGV modes are indeed not supported anymore due to the change of boundary conditions. In that case, there is a transition from ZGV modes to edge resonances [2], which are also localized vibrations, and at different frequencies than ZGV modes. In the case of adhesively-bonded plates, the Lamb modes of each plate are coupled through the adhesive layer, giving rise to change and/or

creation of ZGV resonances. Their frequencies are tightly linked to the bond strength [3], but so are their quality factors. Yet, the use of ZGV modes to localize and characterize a crack or the use of their damping to quantitatively assess the bonding strength of a bonded assembly remains unexplored. We are proposing to use the effects that a change/a creation of boundary conditions has on the ZGV Lamb modes to detect cracks in plates and to give quantitative parameters associated to the bonding strength of bonded plates. Line-scanning experiments are performed across the samples with a pulsed laser delivering 8 ns pulses for the generation and a two-wave mixing interferometer for the detection. According to the experimental results, the use of ZGV mode and edge resonance to detect cracks in plates is promising, as shown in the figure depicting the image of a cracked glass plate thanks to the disappearance of the ZGV mode at the crack locations. A thoughtful analysis of the temporal evolution of ZGV resonances in bonded plates allows to extract characteristic damping times and differences of frequencies for quantitative discrimination of different bonding strength. The ZGV Lamb modes are therefore demonstrated to trigger the possibility of locally characterizing confined changes of boundary conditions. FIG. 2D image of a cracked plate showing the amplitude (in dB) of the power spectral density at the expected ZGV frequency.

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Towards a more accurate contact law for describing the nonlinear response of closed rough interfaces

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Modelling rough contact interfaces with high accuracy requires the knowledge of several interfacial parameters, which affect significantly the dynamic behaviour of a system. Nonlinear interaction between propagating waves and contact interfaces is examined here by a numerical and experimental approach. The present analysis focuses on compression behaviour of a contact interface, based on a nonlinear interface stiffness model. The contact stiffness is described by a nonlinear function of the nominal pressure. Based on experimental results for aluminium-aluminium contact [1] and results presented in literature (often derived from power law [2] [3]), different contact stiffness laws are considered. While the contact stiffness for high pressure is quite well documented and often described by a power law, for low pressure few data are reported. Such issue is investigated in this work, by testing different laws mainly differentiated by the low-pressure behaviour. The test configuration consists in studying the non-linear dynamical response to an impact type excitation. Numerical results derived from the proposed laws are compared to experimental data in order to determine and validate the most accurate contact law. First, the analysis features the dependence of the dynamic response of the system to the contact parameters, specifically to the contact stiffness. Fundamental and second harmonic magnitudes, as well as the fundamental frequency, are found to be in a qualitative agreement with experimental measurements, particularly for one configuration of the implemented law. This work shows how the non-linear dynamical response of a system can be exploited to identify the main parameters of the contact interface law.

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Particles levitation in air using wideband ultrasonic waves

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We investigated the possibility of controlled levitation of particles in the air under the influence of wideband ultrasonic waves. We examined the interference field formed by the emission of signals with linear frequency modulation (LFM). It is proposed to use two counter-directed source arrays focused at the center. The focusing of the source arrays is achieved due to the fact that the elements of the array are placed on the surface of the sphere in a certain sector. Then the focus point is the center of the sphere at any radiation frequency. When any signal is applied to all elements of the array, focusing of the signal is achieved in the center of the sphere. When a monochromatic signal is applied, a levitation region elongated along the axis of the lattice system is formed. We consider the case when the distance between the radiating arrays is several times larger than the size of the aperture of the arrays. Then the particles are grouped into pressure nodes of standing waves in increments of half the wavelength. However, a single local minimum of potential for selective control of an individual particle is not provided. The simultaneous levitation of many particles lined up is supported. In a number of applications, it is necessary to support the levitation of only one particle and in a given position in space.

It is proposed to use a wideband signal in the form of a linear frequency modulation signal to ensure the only stable position of the levitating particle between two focused emitter arrays. We consider LFM with increasing frequency. If the same LFM signal is supplied to both counter-directed arrays, then exactly in the middle between the arrays the interference of counterpropagating waves at the same frequency is always ensured. What forms nodes and antinodes of standing waves in the center. When shifted from the center, the interference of counterpropagating waves at different frequencies occurs. Moreover, if you move along the axis of the system to the left array, interference of a higher-frequency signal from the left array with a signal at a lower frequency from the right array will be observed. With this interference, a quasi-standing wave is formed with nodes gradually moving to the right. Moreover, the speed of the nodes will increase with a strong deviation from the center. Similarly, when shifted to the right, the movement of interference pressure nodes to the left will be observed. Such a distribution of the field forms the field of forces of the pulling particle in the center between the arrays. This will ensure the only stable position of the particles. If it is necessary to move particles along the axis of symmetry between the arrays, it is proposed to trigger signals in oncoming arrays with a time shift. Then the interference point, the field at one frequency will shift towards the array, where the signal is triggered with a delay. It is assumed that the signals are played cyclically, since it is impossible to radiate LFM with an infinitely increasing frequency. The longer the repetition period, the more stable the particle levitation. When switching the radiation frequency from maximum to minimum, a jump in the position of local nodes will be observed. However, since the frequency band from 38 kHz to 43 kHz is considered in a real levitation setup, the jumps in the position of the nodes will be insignificant.

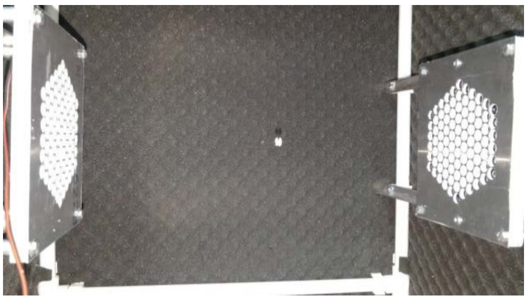

Figure 1: Photograph of levitating particles in a wideband ultrasonic field

Experimental studies have been carried out, confirming the applicability of the proposed concept. Fig. 1 shows photograph of the levitation of foam polystyrene particles in an ultrasonic field with LFM from 38 to 43 kHz. The distance between the array of the emitters is 36 cm, in each array there are 91 emitters MA40S4S. As expected, a grouping of particles into one or two nodes of standing waves from oncoming emitters is observed. When backfilling particles from the side, they were drawn into the central region, where their position was stabilized.

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Poster presentations

P1. Weak-dispersion and high-efficiency multilayer space-coiling metamaterial

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Acoustic metasurfaces have received wide attention due to the unusual capability of wavefront manipulation within subwavelength space. However, the conventional metasurface surfer from narrow bandwidth, which originates from the unavoidable wavefront distortions resulting from the strong dispersion or the low transmission efficiency, resulting from the impedance mismatching of their building blocks [1-3]. In this work, we propose a sandwich-like-structured metamaterial that is low dispersive in a larger refractive index range and highly transparent over a wide bandwidth. The metamaterial is comprised of a core layer and four different auxiliary layers which are constructed by space-coiling structures. The core layer has a tunable refractive index for wavefront manipulation and the four auxiliary layers have gradient impedance for high transmission efficiency. The theoretical analysis, show as well as numerical simulations, that the proposal has a low-dispersion refractive index with a flexible tuning range of 2.3 to 4.8 and broadband near the unity efficiency. This low-dispersion impedance matched metamaterial is a competitive candidate as a building block for broadband acoustic metasurfaces.

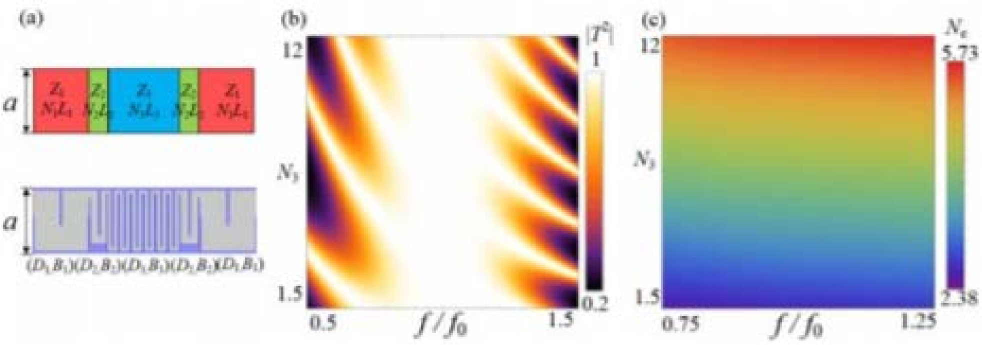

Figure 1: (a) Schematic diagrams of sandwich-like design (top) and the space-coiling based multilayer cell (bottom) [3]. (b) And(c) The transmission efficiency |T2| and effective refractive index Ne of sandwich-like metamaterial as functions of frequency f and core layer refractive index N3. Near unity transmission is observed in the band of 0.75 f0 to1.25 f0, within which the metamaterial is weak dispersive in a large refractive index range.

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P2. Gradient Space-coiling Metamaterials for High-transmission Negative Refraction

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The past decade has witnessed the rapid growth in the study of the negative index materials, which show novel applications such as negative refraction and subwavelength imaging [1]. However, extensive applications of the phenomenon of acoustic negative refraction are limited by the energy loss caused by impedance mismatching and resonating blocks [2-3]. In this work, we show that the acoustic negative refraction with ultra-high transmission can be obtained via the gradient space-coiling metamaterials. We find that both the effective density and bulk modulus of the metamaterials are simultaneously negative in the sense of the effective medium, accompanied by nearly perfect impedance matching. The negative refraction effects with the impedance matched prism and plate are numerically demonstrated and the transmission coefficients are higher than 90% with scattered-wave energy less than 4%. The subwavelength imaging effect of the superlens based on the proposed metamaterials are also presented and the super resolution beyond the diffraction limit and ultra-high efficiency are evidenced.

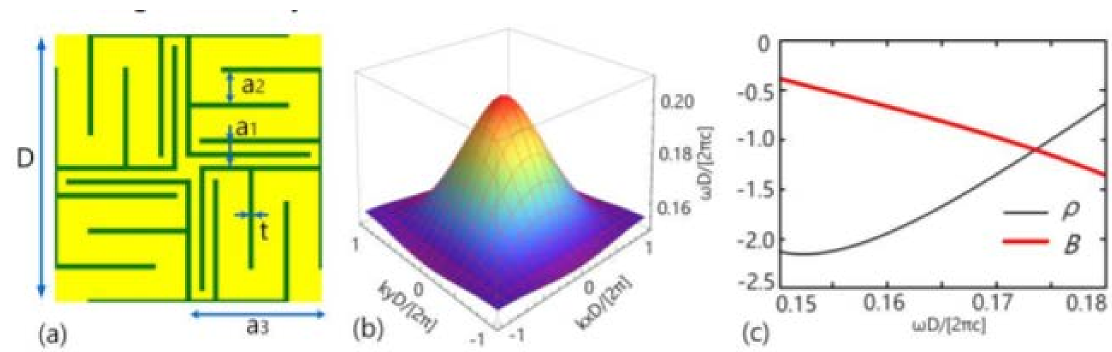

Figure 1: (a) The schematic diagram of the gradient metamaterial [4]. The hard solid plates (green solid lines) inserted into the background fluid (yellow color) have a thickness t=0.02D, where D is the width of the metamaterial unit. The fluid channels have two different widths a1=0.032D and a2=0.112D. (b) A surface plot of the negative band over the whole Brillouin zone. (c) The relative effective density ρ and bulk modules B.

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