DEPARTMENT OF ELECTRONIC & ELECTRICAL ENGINEERING

University of Strathclyde Engineering

Centre for Ultrasonic Engineering

Research Thematic Areas

Current Project Descriptors

April 2013

CUE Overview

The Centre for Ultrasonic Engineering (CUE) has a broad range of research thematic areas, supported by a multi-disciplinary research team comprising engineers (EEE and Mechanical), scientist (physicists, polymer/materials and biological) and mathematicians. CUE has four main research themes: NDE, Bioacoustics, Industrial Process Control and Generic Transducer Design. Figure 1 illustrates the core technical competencies underpinning these research themes.

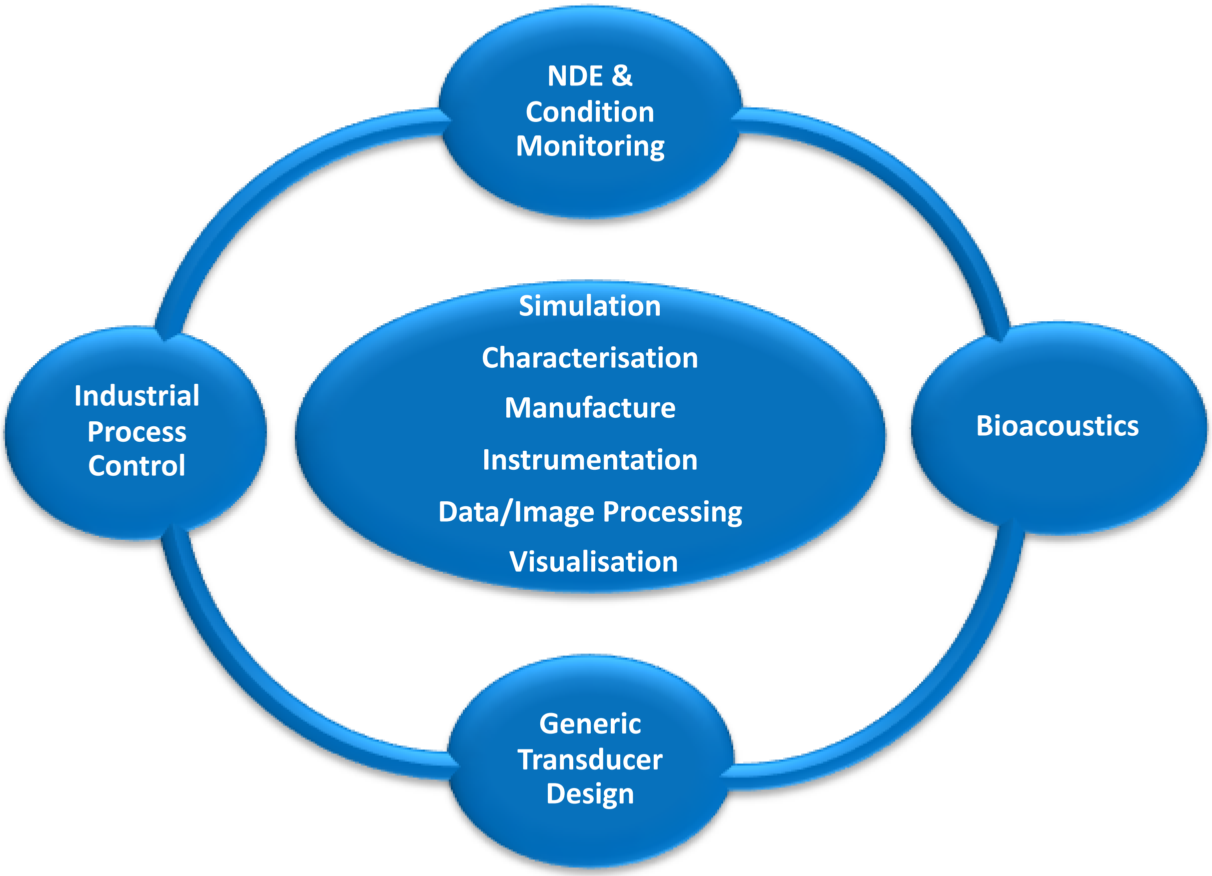

Figure 1 *CUE Research Themes and Core Competencies*

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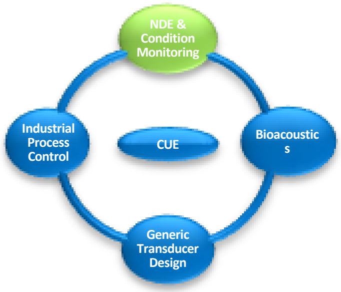
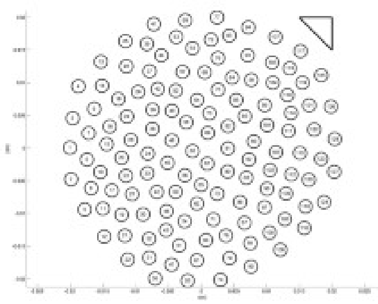
Large Aperture 2D Ultrasonic Array for Inspection of Fibre-Reinforced Composites



Jerzy Dziewierz, Anthony Gachagan

Collaboration between EPSRC, RCNDE, Rolls-Royce and University of Strathclyde to research, design and build 2D Sparse Ultrasonic Phased Array for inspection of airframe components. The project yielded a number of innovative techniques in probe design tools and probe manufacturing technology, and has been successfully followed up with an Impact Accelerator Account Grant to build a permanent, full scale demonstration unit for the new probe and related signal processing techniques in Rolls-Royce facilities.

Completed 2D phased array probe, active sensing area diameter 50mm.



Sparse Poisson disk element layout reduces grating lobes below noise floor level, allowing for better resolution and controllable image contrast.

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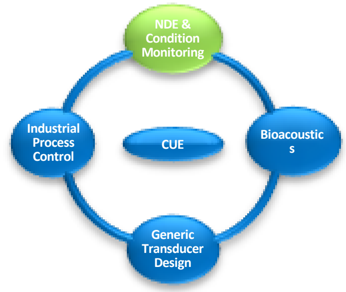
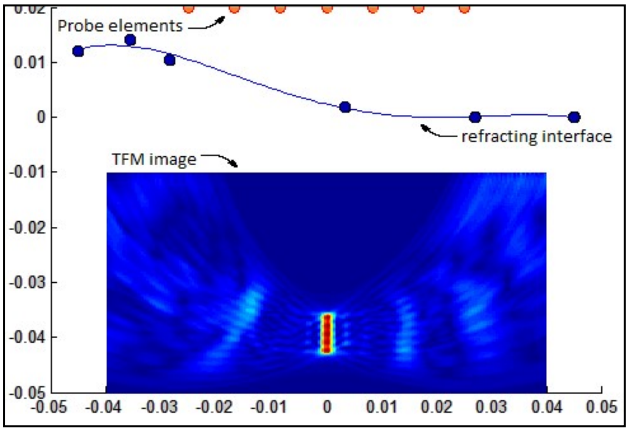


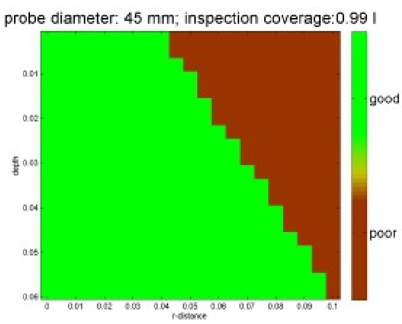
cueMAP – Ultrasonic Probe design tool based on versatile, ultrafast software beamforming technology

Jerzy Dziewierz, Anthony Gachagan

The new software allows evaluation of probe imaging capability indicators like resolution, contrast, SNR, coverage, for 1D and 2D phased array probes, taking into account probe characteristics, and the effects of novel signal processing techniques like TFM or PCF(Phase Coherence Factor) imaging, and other. A novel formulation of refracted ray equation allows for unprecedented speed and accuracy of the computations, allowing interactive design of inspection scenario.



The new, realtime software signal processing code generates TFM images taking into account effects of refraction.



Coverage plot for optimised probe design to maximize inspection coverage, given image quality parameters: resolution<2mm, contrast>35dB.

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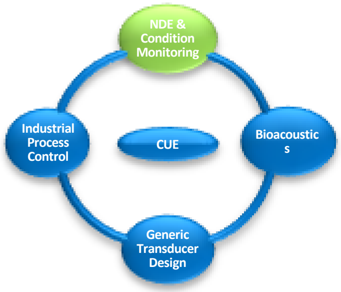
New Array Methods for the Ultrasonic NDE of Difficult Materials: Advanced Array Beamforming



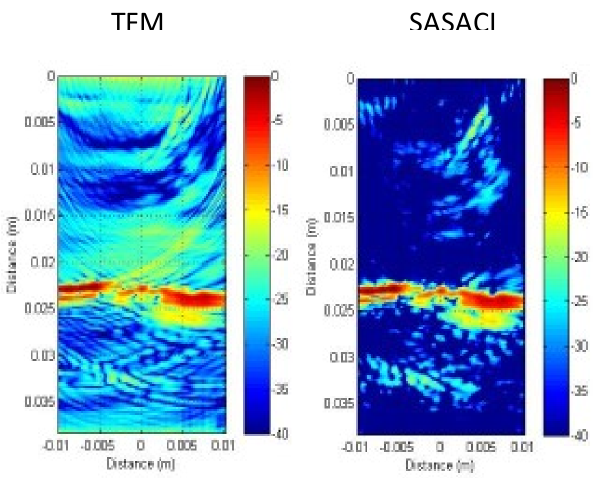
Tim Lardner, Minghui Li, Anthony Gachagan

To enable the manufacture of more efficient and safer machines, a new generation of materials must be used in their construction. Aircraft engines are subject to more stress than ever before and power station turbines and pipes are carrying hotter steam at a higher pressure. Materials used in the construction of these parts must be more durable than their predecessors. New alloys have been found that exhibit the requisite material properties, but they are often difficult to inspect due to their grain structure attenuating and scattering ultrasonic waves.

This project investigates advanced and adaptive beamforming methods that can be used to overcome the difficulty that the inspection of material poses. The Full Matrix Capture (FMC) is used to gather all combinations of transmit-receive data from an ultrasonic array so that beamforming can be applied in post-processing. This allows for more advanced methodologies to be used, as well as the possibility of applying multiple techniques.

In ultrasonic NDE, the Total Focusing Method (TFM) is considered the gold standard of inspection; however it is unable to detect many defects in highly scattering materials. New, advanced techniques are being investigated, such as Phase Coherence Imaging (PCI), the Generalised Coherence Factor (GCF) and DAX (Dual Apodization with Cross-Correlation). A novel beamforming technique was developed within CUE by Lardner et al [QNDE 2012] which reduces incoherent noise from sidelobe reflections. This technique is known as Spatially Averaged Sub-Aperture Correlation Imaging (SASACI).

Results from SASACI have been promising. The images below show a comparison between TFM and SASACI for a defect within a stainless steel weld. The defect is far more visible in the SASACI image and the average noise level is lower.



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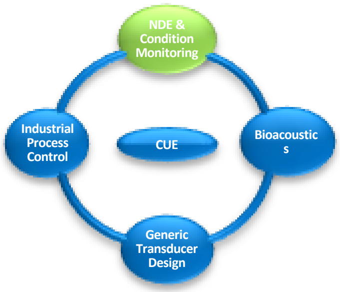
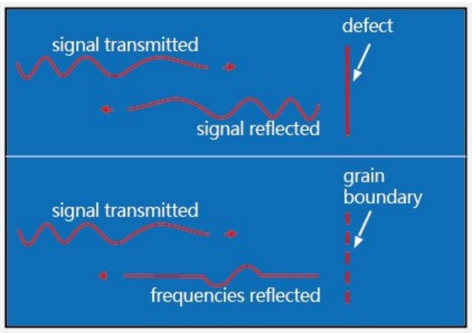
Adaptive Frequency and Spatial Diversity Processing for Ultrasonic Non-Destructive Evaluation (NDE) of Difficult Materials



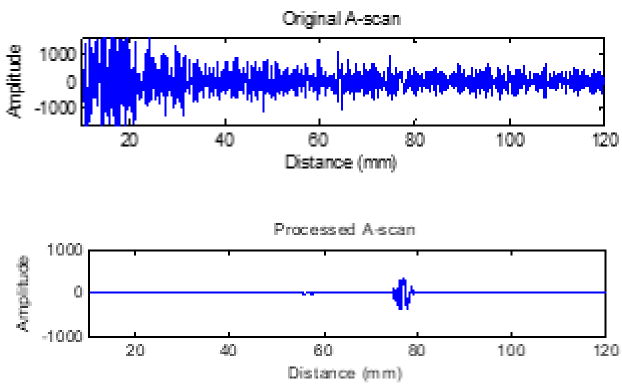
Rui Gongzhang, Minghui Li, Anthony Gachagan

In industrial NDE a lot of materials are difficult and contain strong structure noise. To enhance the detect ability and reduce noise, a range of techniques based on spatial diversity and frequency diversity are investigated.

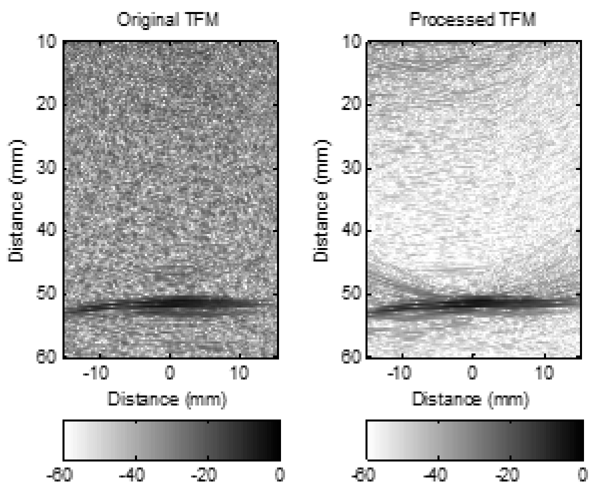
In particular, the spatial diversity arising from multiple distributed transmitting and receiving transducers and the frequency diversity arising from multiple interrogation frequencies will be explored to de-correlate and suppress the speckle and clutter noise. These two approaches can be further combined.



Spectrums differences between defect and noise



Frequency diversity result for single A-scan trace



Spatial-frequency diversity combination

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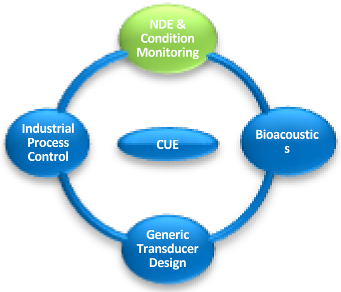
Advanced Spectral Techniques for the Ultrasonic NDE of Difficult Materials



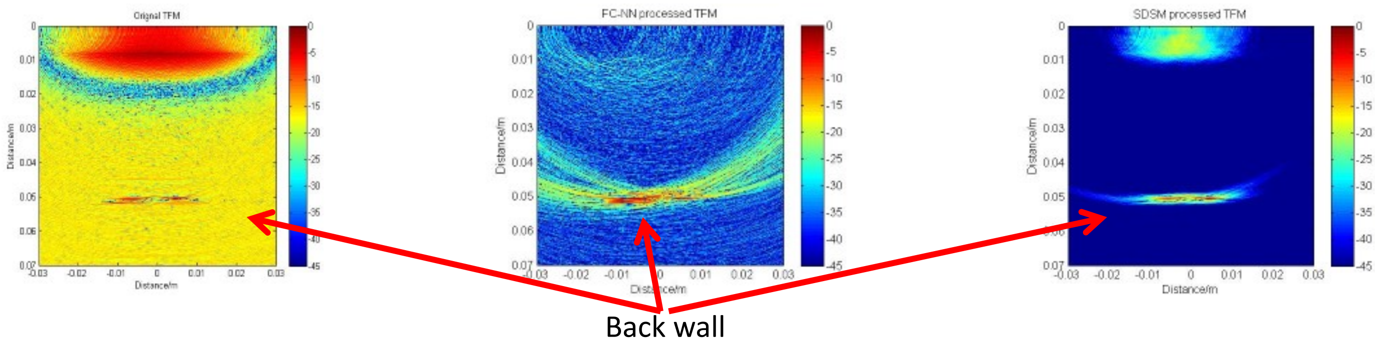
Bo Xiao, Richard O'Leary, Minghui Li, Anthony Gachagan

Introduction

In ultrasonic non-destructive detection (NDE) of acoustically scattering materials, such as concrete, fibre-reinforced composites, target (flaw) echo is always obscured by grain noise. It motivates the development of new methods for ultrasonic NDE of such materials

Noise reduction techniques

- Frequency compounding with neural network (FC-NN): implement frequency compounding into artificial neural network
- Spectral distributions similarity measure (SDSM): measure the similarity between spectral distribution of each focusing point (delay-and-sum) and statistical noise spectrum distribution



Comparisons between two developed methods and original TFM

Spatially resolved acoustic spectroscopy (SRAS) finite element modelling

- Cheaper than Electron Back-scattered Diffraction (EBSD), lower polish requirement
- Benefits the development of noise reduction techniques

Novel wide bandwidth transducer/array

- Noise reduction technique results guide the design of novel array
- Benefits with noise reduction each other

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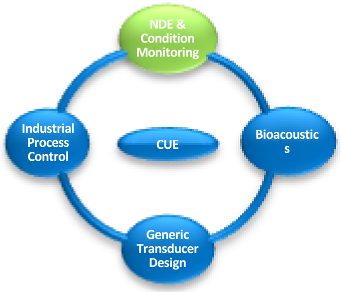
Automated Scanning for the Inspection of Complex Components (ASICC)



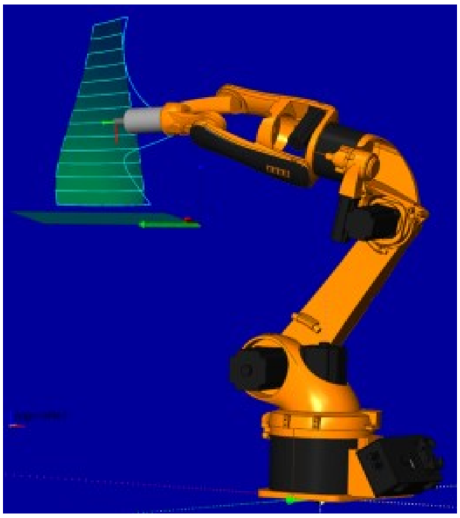
Maxim Morozov, Gareth Pierce, Anthony Gachagan

The overall aim of this core research project is to develop a demonstrator NDE test cell within the FIRST lab at Strathclyde that will incorporate automated NDE tool path generation for complex shaped components.

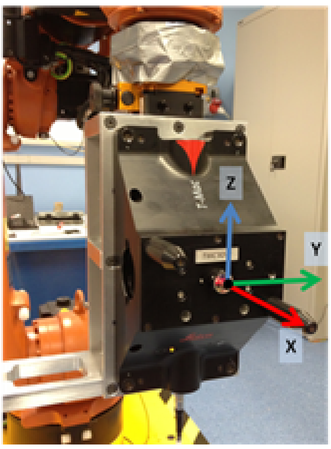
Project Objectives:

1. Integrate NDE technologies with established industrial robotic automation to create a flexible inspection process that could be implemented on low cost robots
2. Investigate automated toolpath generation for complex shaped components
3. Understand constraints on scanning speeds for complex geometries
4. Investigate and improve positional accuracy of robotic positioning systems

Automation of non-destructive inspection (NDI) of engineering components and structures represents one of the strategic objectives of many industries. It enables to increase accuracy, precision and speed of inspection while reducing production time and associated labour costs in contrast to manual inspection. The use of robots can provide additional flexibility and autonomy to automated NDI integrated into manufacturing process of components with very complex geometry.

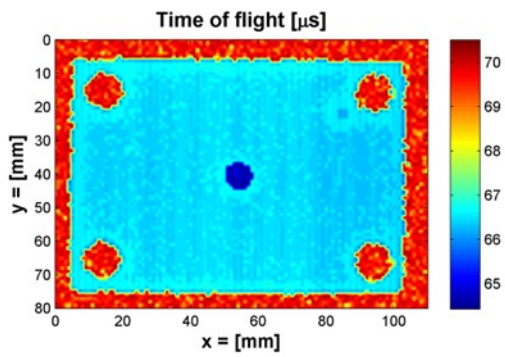


In this project we investigate the application of industry standard 6 axis robots (KUKA KR5 Arc HW) to deliver NDE measurements to components with complex surface geometries. We explore the potentials for reverse engineering of components with missing CAD models by means of Coordinate Measuring Machine (FARO arm and Verisurf software) as well as automated tool path generation (MasterCAM and Robotmaster software).



The project also aims at improving path trajectory through real time measurement of tool position, for instance, by means of a laser tracker (Leica AT901).

Integration of an NDE probe (ultrasonic or eddy current) into robot tool is another line of research of this project.



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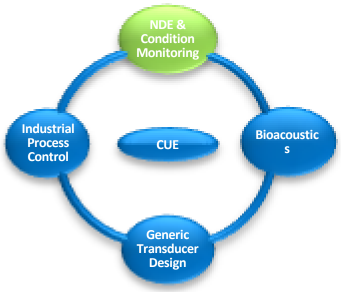
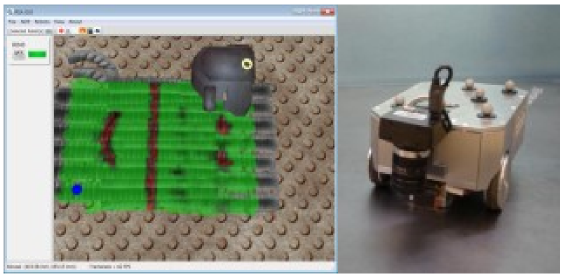


Automated Non-Destructive Testing

Gordon Dobie, Gareth Pierce, Anthony Gachagan

RCNDE Core / General Research

The research goal is to create an autonomous team of robots that collectively create a 3D NDE map of a structure using a variety of sensor payloads including ultrasonic, visual and magnetic. A simplified example is shown on the right. Key research themes include robot path planning and positioning, sensor design, data fusion and reconfigurable guided ultrasonic wave imaging.

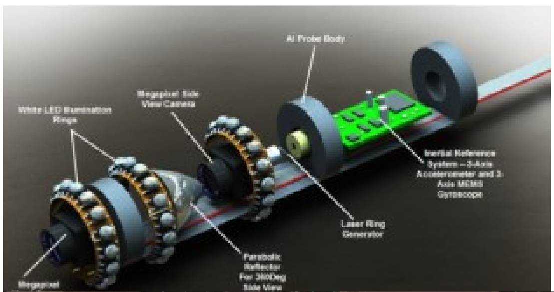


Automatic Ultrasonic Robotic Array (AURA)

AURA is a collaboration between Doosan Power Systems, Alba Ultrasound and the University of Strathclyde with the objective of creating a novel small form-factor autonomous reconfigurable ultrasound phased array inspection robot for NDE. The technology will significantly reduce manual labour over current inspection regimes as well as enabling inspection of inaccessible and/or hazardous areas. The major innovation is embedding ultrasonic phased array technology into a small form-factor robotic vehicle, overcoming issues in ultrasonic coupling, miniaturised electronics and high power density.

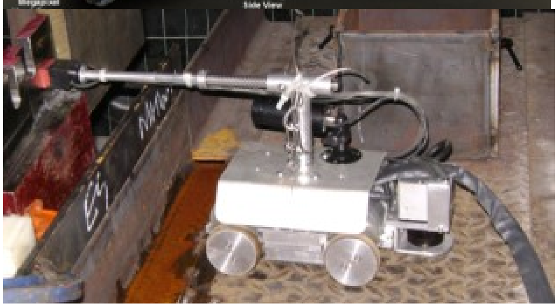
Mosaicing for Automatic Pipe Scanning (MAPS)

MAPS is a collaborative feasibility study between Inspectahire, Scyron and the University of Strathclyde. The project considers the development of an interactive 3D remote visual inspection system for pipe (concept shown on right). Unlike conventional systems, it creates an interactive 3D textured map which can be analysed offline to obtain accurate information about the location and nature of defects.



Technology Transfer

Dr Dobie and his colleagues worked with NNL to create the robot shown on the right which successfully inspected a critical vessel in the Magnox Reprocessing Plant at Sellafield. The inspection represented a significant challenge because human access into the vessel's cell (a concrete compartment of the building containing the vessel) was not possible due to high radiation levels. This presented an ideal opportunity for Strathclyde's miniature robotic vehicles which can be deployed and retrieved through a small inspection hatch in the cell's wall. The robot successfully navigated across the cell to perform a series of ultrasonic thickness measurements. These provided the evidence needed for continued safe operation of the plant. Dr Dobie is also working on exciting technology transfer projects with Silverwing NDT and Syngenta.



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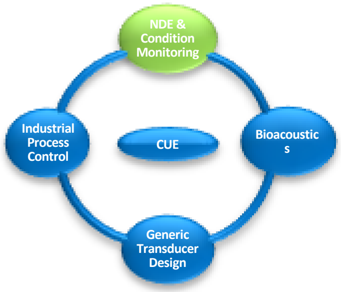
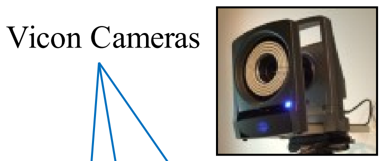
Positioning Systems for Robotic NDE

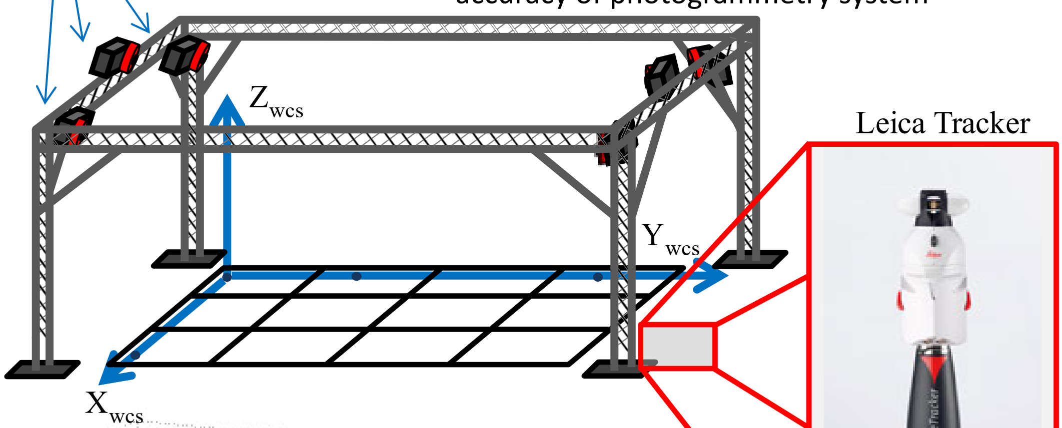


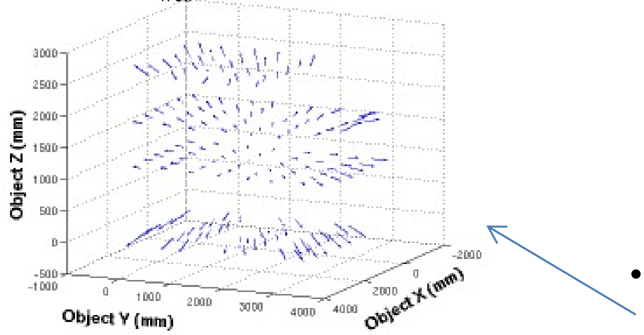
Rahul Summan, Gareth Pierce

In carrying out a task, a key aspect for any robotic system is determining its location with respect to a frame of reference. In the context of robotic NDE using mobile robots (Remote Sensing Agents) accurate positioning is needed to return to the same position across multiple inspections in order to investigate the same area of a structure. In addition, positioning accuracy directly affects the quality of NDE sensor based images assembled from location data. In the context of using fixed arm (KUKA Arc5) robots for scanning complex parts, the accuracy of end effect placement can be limiting factor in the complexity of the object that can be scanned. The focus of this research is to investigate positioning methods for the mobile and fixed arm sensor delivery platforms in CUE.

- Error characterisation of large volume (7m x 4m x 4m) photogrammetry system (dense measurements) using laser tracker (sparse measurements)
- Investigation of calibration methods to improve accuracy of photogrammetry system







- Test object swept through volume and tracked by both systems
- Error vectors of Vicon measurements with respect to Leica measurements (Arrow head Leica measurements)

The place of useful learning

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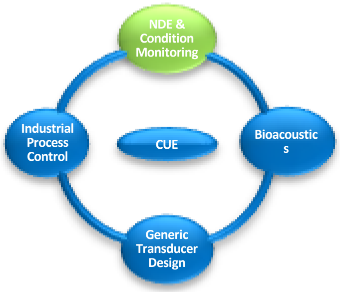
Autonomous Remotely Deployable NDE



Charles Macleod, Gareth Pierce, Anthony Gachagan

For structural monitoring applications, the use of remotely deployable Non Destructive Evaluation (NDE) inspection platforms offer many advantages, including improved accessibility, greater safety and reduced cost, when compared to traditional manual inspection techniques. Remote inspection facilitates the potential for rapid scanning of large areas and volumes in hazardous locations where manual inspections would be costly to perform safely. The requirement for autonomous NDE systems has driven research and development in robotic inspection platforms capable of remotely accessing structures and undertaking detailed NDE using a variety of specialised sensors and payloads.

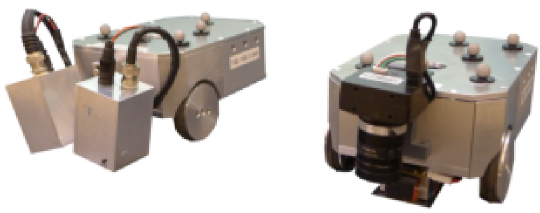


Figure 1: Remote Sensing Agents

The current Remote Sensing Agents (RSA) (Fig 1.) developed within the Centre for Ultrasonic Engineering feature a fleet of differential drive magnetic wheeled crawlers capable of performing inspection tasks using a variety of sensor payloads including Air-coupled Ultrasound, Eddy Current Array, Magnetic Flux Leakage (MFL) and visual based systems.

Figure 2: Aerial Inspection Platform

Although successfully used for real inspections these RSA's have obvious access limitations and on-going research has investigated the design and use of aerial based platforms (Fig. 2) to allow more flexibility in inspections not constrained to gravity or limited to ferromagnetic material. Such a robot will readily allow the inspection of complex structures not only constructed from ferromagnetic metal but also common composite materials, such as polymers and concrete, in true three dimensional space.

A common problem for both manual and remote deployment approaches lies in the intrinsic stand-off and surface coupling issues of typical NDE probes. Both ultrasonic and eddy current sensors require careful control of surface coupling and stand-off for repeatable measurements. The associated complications of these requirements are obviously significantly exacerbated when considering remote deployment, and hence simple visual techniques are often the principal sensor used in such scenarios.

A growing area of research is based on artificial tactile sensors systems that are surface compliant removing issues surrounding the surface condition and preparation. A novel active whisking sensor, based on the vibrissae or rats and mice, has been evaluated to highlight the surface roughness measurement and profile scanning sensory information applications.

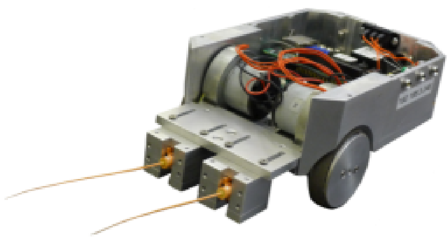
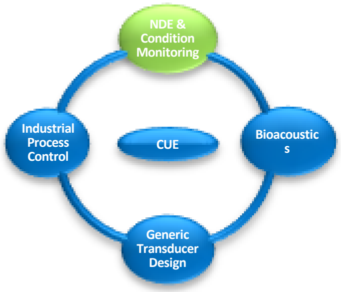


Figure 3: Active Tactile Sensors



Experimental Evaluation of Difficult Materials Project: NDE Test Samples

John Mackersie, Anthony Gachagan

An EPSRC/RCNDE targeted project to investigate new ultrasonic array techniques appropriate for application in highly scattering or attenuating materials. The four main research themes are: experimental data collection of both NDE data and material microstructure characterisation; wideband ultrasonic transducer design and development; ultrasonic array system modelling; and signal/image processing through frequency domain techniques and advanced beam forming.

Specific areas of activity include: liaison with industry and University partners; acquisition of samples of materials relevant to industry such as forged stainless steels and cast Inconel alloys; and co-ordination of characterisation of these materials by methods such as spatially resolved acoustic spectroscopy (SRAS) and electron backscatter diffraction (EBSD).

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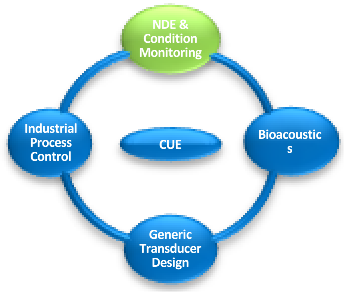
WoodSonics: A Cost-Efficient, Automated, Machine Strength Grading System for Sawn Timber

John Mackersie, Francesco Guarato, Anthony Gachagan



WoodSonics is a project funded by the European Commission's Seventh Framework Programme FP7 "Research for the benefit of SMEs". Due to the high cost of machine strength grading, visual techniques are used at most SME sawmills. However, this is a slow process which does not detect internal defects. WoodSonics aims to produce a cost-efficient in-line wood grading machine which uses on ultrasonic rolling transducer to detect, identify and localise specific defects in pieces of structural timber.

Specific areas of activity include: performing ultrasonic measurements on samples of sawn timber of the relevant soft and hard woods; development of appropriate transducer designs and incorporation into a mechanical roller system.

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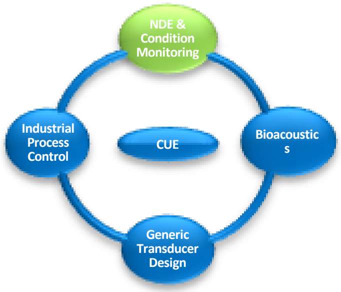
NDE of Complex Shaped Components



Jie Gao, Anthony Gachagan, James Windmill

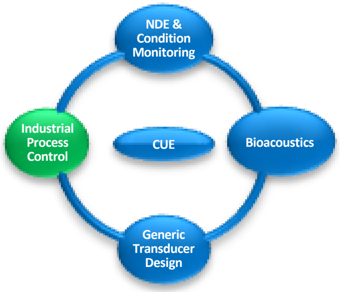
Research on the matching layer technology for air-coupled transducers:

Following the undergraduate final year project which is related to the air-coupled transducer design and the piezocomposite material, the PhD research now plan to improve the reliability of the matching layer's manufacturing process which is always easy to fail. There are many factors which can influence the quality of the matching layer such as the pressure, the volume of the silicone rubber, and the waiting time. After manufacturing a number of matching layers by using the control variable method, find the best parameter for each factor and try to find a way to increase the quality.

Manufactured air-transducer matching layers

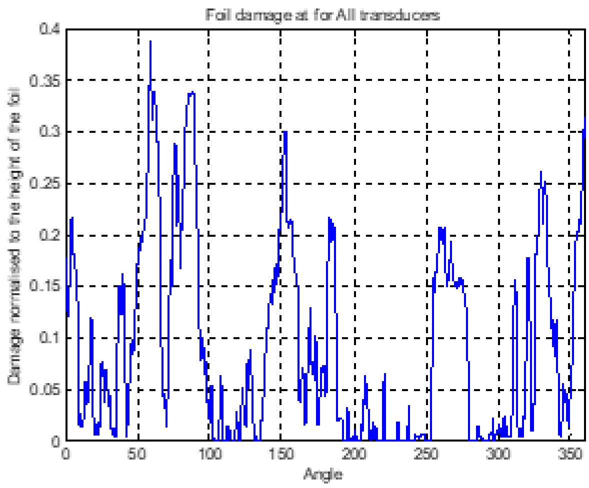
Reactor Design for Sonochemical Processing

Tapiwa Mutasa, Dr A Gachagan



High power ultrasound has shown great potential for commercial application in material processing with significant improvements to product yield, quality and reduction in cost and risk. For this technology to be economically viable, reactors capable of processing larger volumes have to be designed. This research is therefore about this process.

The phenomenon responsible for these effects is cavitation which results from large pressures in the liquid. Reactors present an acoustic environment with complicated acoustics as well as an ensemble of factors which factor into the pressure distribution. Through the use of finite element modelling, the interaction and roles of various factors have been theoretically studied. Further modelling and fine tuning have resulted in a final design of a reactor with a processing capacity of 13L being driven at 3 distinct frequencies. Multiple frequency design approach is observed to result in a direct superposition of cavitating space and therefore a linear scaling of cavitating volume thus identifying a target for further scaling work.



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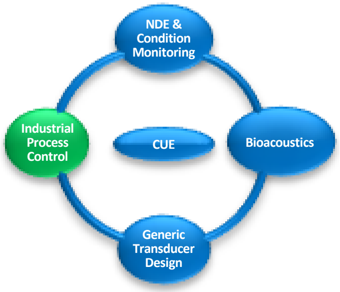
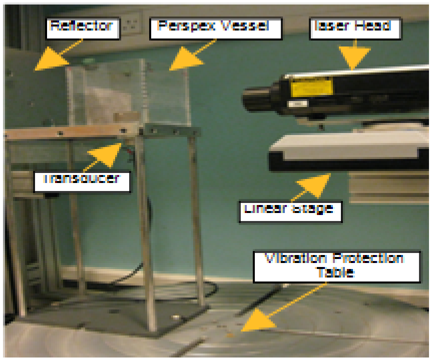


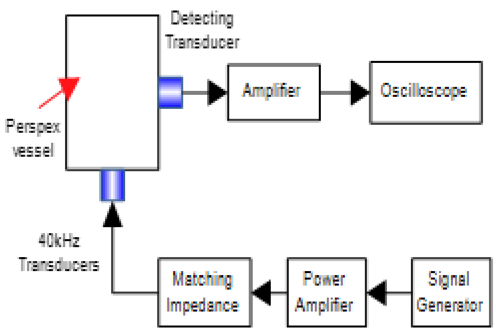
Non-invasive measurement technique to monitor acoustic cavitation

Kornpatsitt Promasa, Tony Gachagan and Gareth Pierce

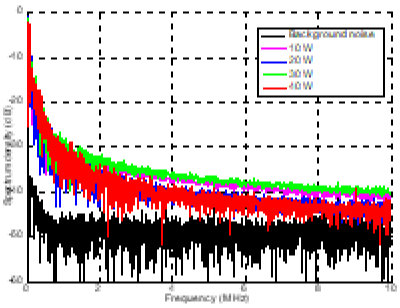
High power ultrasound applications induce the cavitation in the load medium, which leads to the mechanical and the chemical effect. It is necessary to measure the cavitation under the influence of a high power ultrasonic field. However, conventional techniques and sensor technology are not suitable for use because the sensor used for detection suffers from damage in these conditions. Therefore, a non-invasive measurement technique: Laser Doppler Velocimetry (LDV) and a broadband non-invasive probe specifically designed, undertaken using the acoustic emission technique, is developed. The acoustic cavitation was conducted to evaluate the relationship between an acoustic broadband emission signal and the amount of cavitation activity acquired from BIE calculation in many power levels. The amount of cavitation activity is calculated by broadband integrated noise energy (BIE) in the frequency range between 1 to 5 MHz in many power levels.



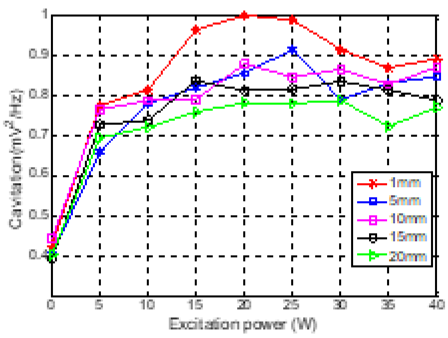
(a) LDV measurement system



(b) broadband non-invasive transducer measurement system



(a) Detected acoustic spectrum



(e) Relationship between cavitation and input power

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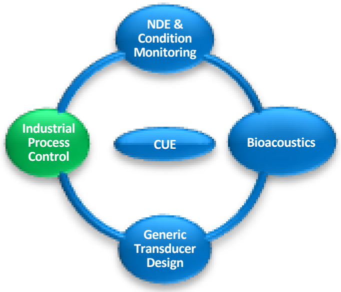
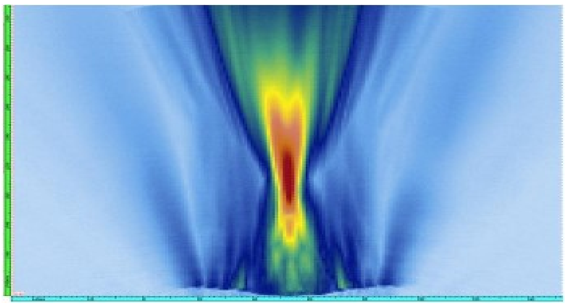
High Intensity Focussed Ultrasound: high power arrays and low power monitoring systems



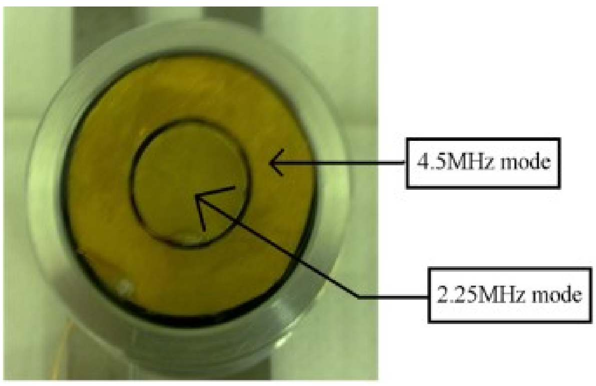
Chuangnan Wang, Tony Gachagan and Richard O'Leary

- High power ultrasound is increasingly employed in a number of biomedical and industrial applications. In biomedicine, high intensity focussed ultrasound (HIFU) is used to induce necrosis of some malignant tissue within the body. In industry, high power ultrasonic systems are employed in chemical processing in order to modify the course of a chemical reaction.



Pressure field mapping from a high power array transducer

- Investigation on the application of HIFU techniques to the modification of chemical reactions
- As part of the ultrasonic processing system, monitoring device on this high power ultrasonic process was also investigated and was proposed to integrated into the transducer package to provide feedback on the status of the reaction and thus, provide an ability to control the reaction process.



Dual mode transducer for monitoring purpose

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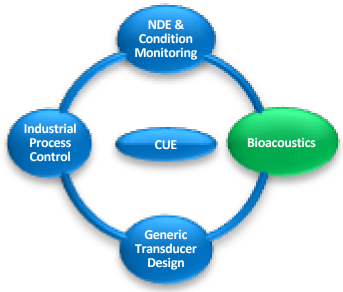
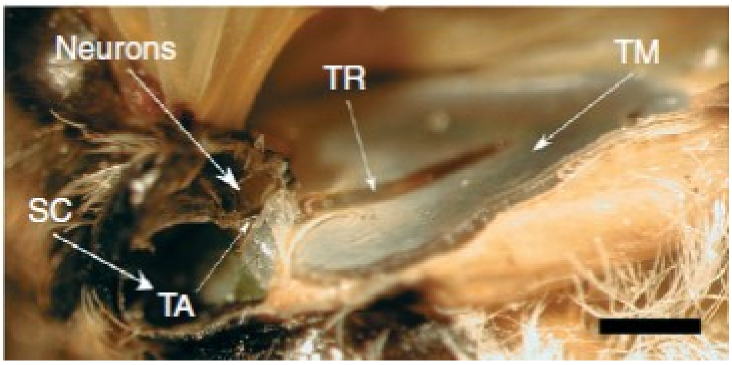
Signal conditioning in hearing – studies of insect audition

Joe Jackson, James Windmill



Hearing has evolved in the animal kingdom to transduce sound in the environment into electrical signals that is the language of the nervous system. Many problems exist for a listener – for example, how to detect the weakest signals, or how to ignore background noise. In its simplest form, an acoustic sensor is a mechanical oscillator, and control of the mechanical parameters such as stiffness and damping can suffice for optimising the sensor – for example, if a large bandwidth is needed, or a specific frequency is of interest. A large subset of animals, however, have evolved active forms of hearing, in which feedback derived from molecular motors adds energy to the receiving oscillator to enhance, compress, or otherwise condition incoming signals.

The research project consists of the study of two different insects – the mosquito and the cicada – in an attempt to understand some of the characteristics of these ears. The mosquito, for example, is a nonlinear oscillator which allows autonomous control of the bandwidth and gain of its sensor. It derives this capability from an enormous number of attached neurones (some 16000) that can generate mechanical force. Similarly, the cicada has a few thousand neurones – each of which ostensibly can generate force. This project seeks to understand the principles behind signal conditioning in these animals, with a view to applying these principles to create novel engineered acoustic sensors.



Mosquito ears (which are nonlinear oscillators) project from the head as two brush-like antennae (left). Dissected ear of the cicada (right), a tympanal (drum-like) ear (TM) where neurones (SC) attach via a lever (TR to TA)

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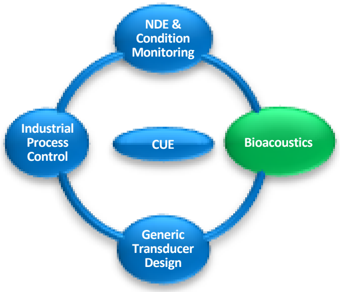
Beam Based Sonar Inspired By Bat Echolocation For Target Localization

Francesco Guarato, James Windmill, Tony Gachagan



Bat echolocation provides us with suggestions for performing target localization through ultrasounds. Target localization would be performed by means of a sonar system equipped with an emitter and two receivers resembling size and mutual displacement of mouth and ears on a bat head. The emitter produces a broadband signal in the ultrasonic range which is reflected back to the receivers from a target. Knowledge is used in this research of the directivity associated with the two receivers in order to distinguish the direction of the reflected signal, while time of flight of these signals are used to calculate the distance between the target and the sonar system. For each receiver, the ratio of the reflected signal is divided by the original signal, for all the frequencies: the ratio is then compared to the beam pattern values of the receiver corresponding to different orientations. The orientations providing the amplitude filtering same as that of the ratio, for each frequency, are collected in both receivers. Only the couple of orientations (one for the left, one for the right receiver) fulfilling opportune geometric relationships given by the geometry of the situation is chosen as the final estimate of target orientation. The calculated distance, along with the estimate of the orientation (defined by azimuth and elevation angles), provides the spherical coordinates describing the location of the target with respect to the sonar system.

In simulation, orientations spanning the beam pattern domain of the receivers are estimated with different accuracy, depending on the area of the domain. Even so, when using the acoustic simulation of the *P. discolour* bat specie's beam pattern, the error values between true and estimated orientations are all less than 5 degrees, this accuracy being comparable to that of some bat species. Further simulations were carried on in order to find the optimal shape which, if mounted on the two receivers, provided them with the beam pattern ensuring the most accurate orientation estimates.

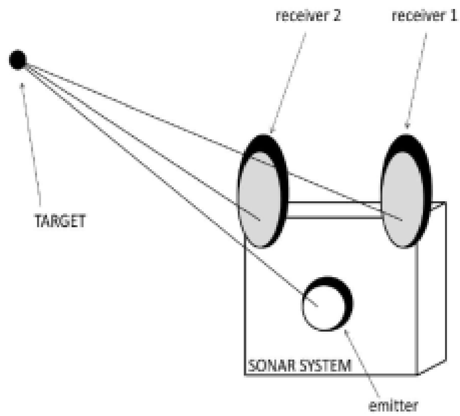
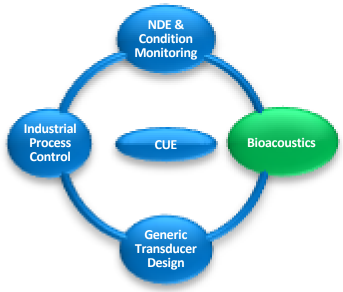


Figure 1: Scheme for the ultrasonic sonar system with 2 directional receivers and one emitter.

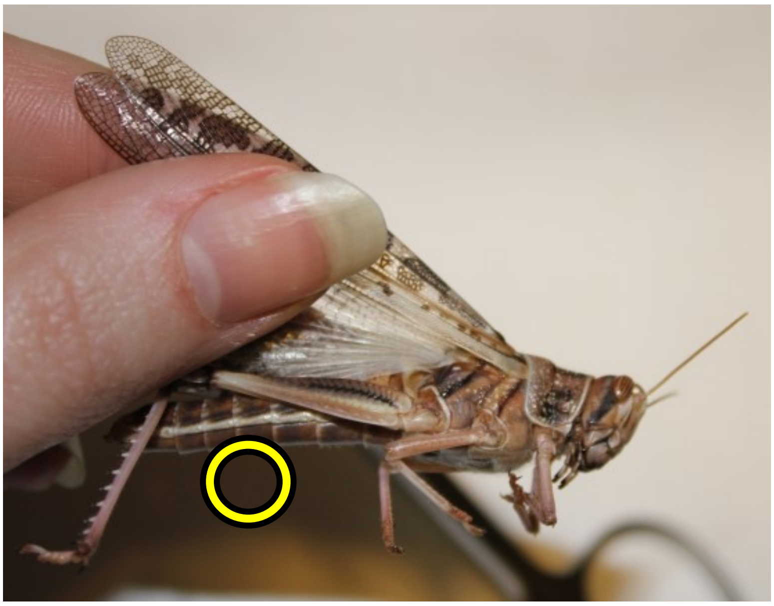
Further simulations were carried out in order to find the optimal shape which, if mounted on the two receivers, provides them with the beam pattern ensuring the most accurate orientation estimates. This search led to a structure composed of two truncated cones sticking onto each other, the upper one having a parabolic flare rate, and assembled together so to resemble a bat ear. This shape will be mounted on the receivers and in building the sonar system that will be used for measurements and experiments on both vehicular and aerial robots during non-destructive evaluations.



Bio-inspired Sound Reception

Shira Gordon, James Windmill

I am interested in how insect hear with their 1mm sized ears. Not only are these natural sound receiving devices small, but they are quite varied. Hearing has evolved at least 7 times in insects each with different mechanisms, utilising membrane travelling waves (locust), lever mechanisms (cicada), and complex air chambers (cricket). I study how aspects of differing environments or environmental conditions affect hearing and sound reception in insects. These include temperature, crowded or gregarious vs solitary locusts, or animal age. Animals that are exposed to different environments while maturing may exhibit 'developmental plasticity', which enables animals to remain best adapted to which micro-environment they experience during growth. For example, locusts exhibit an extreme form of this, known as epigenetic effects, resulting in two phases--solitary (A) and gregarious (B)--differing in appearance, behaviour, and visual capabilities. Recently, it has been shown that gregarious animals have vision that is more specialized for living in a swarm. Conversely, for the hearing sense, our results show solitary locusts are more sensitive, presumably to hear their predators more precisely as they are not protected by the numbers of the swarm. The trade-off between enhanced hearing in solitary animals, presumably for predator detection, and better vision in gregarious locusts for swarming behaviour, highlights the importance of epigenetic effects set forth during development and begins to resolve identify how animals are equipped to match their immediate environmental needs. This work is placed within CUE as we can design bio-inspired transducers on the same principles that we find in natural examples.



Picture of a locust and its ear place on the first segment of its abdomen (semicircle circled in yellow).

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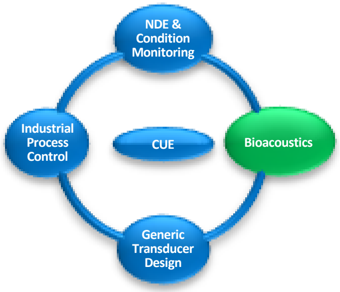
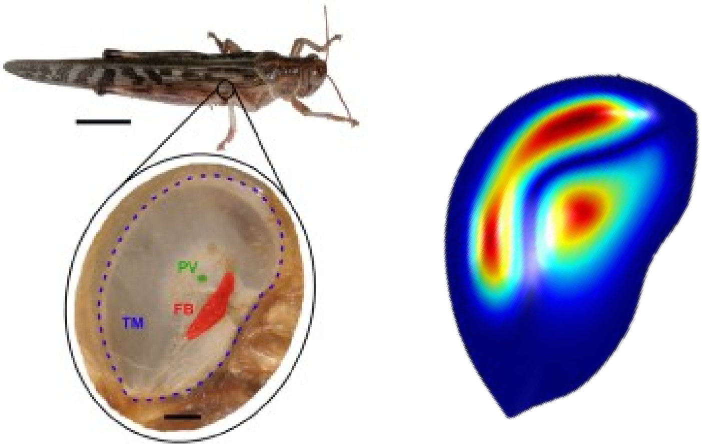
Biologically Inspired Acoustic Systems: From insect ear to MEMS microphone

David Mackie, James Windmill, Tony Gachagan



The research objective is to investigate the material properties of insect auditory systems. Computational modelling of the hearing systems and the application of finite element analysis allows for a better understanding of the highly-evolved design of insect ears and provides an explanation of the observed behavioural response. This work is undertaken with a view to the design of novel sensory systems including the analysis of highly sensitive directional microelectromechanical microphones fabricated from single crystal silicon.

Scanning laser Doppler vibrometry has provided an in vivo analysis of the nanoscale vibration of insect 'ear-drums' otherwise known as tympana. Using known material properties and the characteristic dimensions, complex models are created and a variety of acoustic experiments are simulated. A frequency response analysis of the models shows that a combination of several natural modes of the ear drum contributes to the complex vibrational pattern which is observed on the insect's tympanum during stimulation by biologically relevant sounds.



The same research techniques are implemented in the modelling and testing of MEMS actuator/sensor structures. A combination of two of the structure's natural modes of vibration results in a unique response when the frequency of excitation is within a working range. This mechanical response results in the device displaying directionality, verified by the computer modelling, when the device is excited by an incident sound source at a range of angles.

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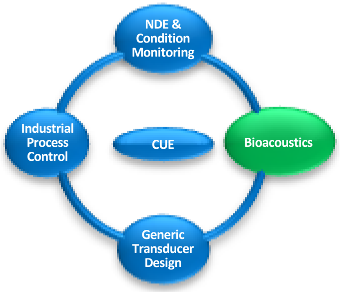
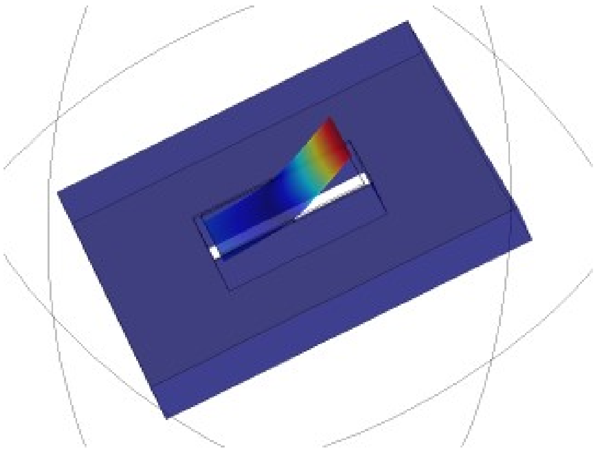
Microscale Acoustic Systems: Bio-Inspired Micro-Electro-Mechanical Systems (MEMS)



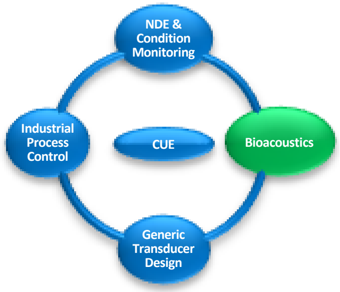
Andrew Reid, James Windmill, Deepak Uttamchandani

The auditory system of the parasitoid fly *Ormia ochracea* has a remarkable directional sensitivity allowing the insect to locate a sound source to within 2º azimuth. This sensitivity, comparable to that of humans, is more remarkable when the scale of the auditory system is considered: the tympanal membranes of *Ormia ochracea* are spaced less than 0.5mm apart. The directional cues available from phase differences and inter aural intensity differences are therefore extremely limited. The key to the fly's directional hearing lies in the coupling of the two tympanums via a flexible cuticular membrane, christened the inter-tympanal bridge. This coupling amplifies the inter-aural intensity difference to 20dB at 45º azimuth and the inter-aural time difference by a factor of 20.

The aim of this research is to apply the coupling mechanic of the Ormiine ear in a Micro-Electro-Mechanical System (MEMS) and therefore develop a new form of directional microphone. In addition to this studies will be undertaken on the Lesser Wax Moth (*Achroia grisella*). Using the moth colony at the Institute for Research Biology an anatomical and physiological study of this auditory system will be undertaken with the view to developing a mechanical model of the function of the system. This moth is known to use sound directionality in order to locate a mate. However, this has been shown through behavioural studies of the moth. This PhD research will thus for the first time consider the acoustics and biomechanics of the sound directionality displayed by the moth.



COMSOL Acoustic Structure Interaction Model of Ormia inspired membrane. The mode shape shown is the combination of rocking and translational modes giving the largest amplitude difference between the ipsilateral and contralateral wings



Biological inspired MEMS microphone

Yangsheng Zhang, James Windmill, Deepak Uttamchandani

The technologies relating to directional microphones have already been developed during the last forty years. However, how to build a directional microphone with higher directional sensitivity and larger signal-to-noise ratio is still the most important research target for researchers. Most of these directional microphones require complex signal processing to get the desired performance. Since the end of the 1980s, a few research groups around the world have started to investigate a biomimetic directional microphone which can further reduce signal processing. This kind of microphone is inspired by the external hearing structure of a parasitic fly *Ormia ochracea*, with mechanical coupling of two membranes with separating distance of less than 500μm. It has dramatic directional sensitivity compared to conventional microphones. Inspired by the mechanical structure of *Ormia ochracea*'s ear (see Figure 1), this kind of microphone is fabricated by utilising MicroElectroMechanical Systems (MEMS) technology. Therefore, it can be commonly applied in mobile communication, navigation, hearing aids, etc. In the current research field, most fabricated products do not have adequate SNR and usually get unwanted noise from environment, which is a big problem for commercial use such as hearing aids.

The major aim of this project is to build a novel biological *Ormia ochracea* inspired directional microphone with better anti-noise capability, higher directional sensitivity and smaller dimensions. In addition, in order to be used in commercial pathways, the new design should have better performance in low frequency audio range. Furthermore, most existing designs are capacitive sensing which bring large noise into the systems, and some designs are optical sensing, but at great cost. This project will investigate a combined or new sensing method to reduce acoustic and mechanical noise in the system with relatively less cost. The designed structure will be simulated in multiphysics simulation software (COMSOL), microfabricated and experimentally characterized in the lab.

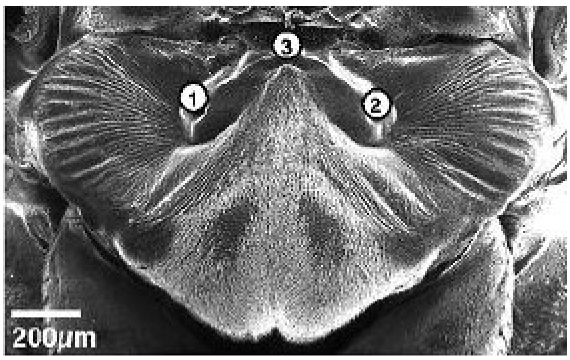


Figure 1.The cross section image of Ormia ochracea's tympana

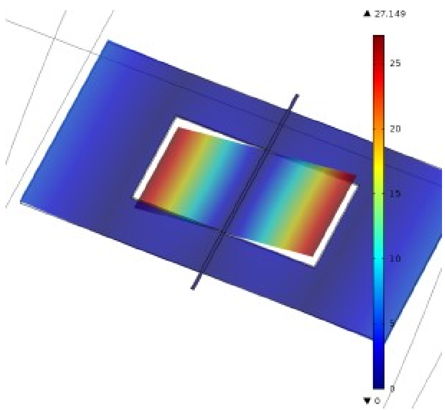


Figure 2. An embryonic design for the project

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