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in Underwater Acoustics

Underwater Acoustics PhD Symposium

University of Bath

16th December 2019

Committee: **Prof Gary Heald (Chair)**
Dr Duncan Williams
Dr Philippe Blondel
Dr Alan Hunter

Session 1 Session chair – Prof Gary Heald (Dstl and Heriot Watt University)

0915 – 0945 **(Invited)** Sonar Design for Object Recognition and Characterisation.
Dr Yan Pailhas – cmre, Italy.

In this talk, we will address the problem of information in sonar images and in acoustical signals. As we naturally focus on image resolution (i.e. the amplitude of the specular), we tend to overlook the signal residual that forms the full echo structure. Secondary echoes come from the intricate interaction between the pulse and the object it-self, therefore containing information about the structure and the material of the object. While the issue of the full deconvolution between echo and insonified target remains an open problem, we will show that by better understanding the physics and by designing new sensors, we can address specific problems including those linked to MCM (Mine CounterMeasure), environmental surveys or offshore exploitation.

0945 – 1000 Imaging Ocean Waves with Sound Waves and Light Waves.
Oscar Bryan– University of Bath, A.J. Hunter, P. Bayle and C. Blenkinsopp

Ocean waves play a crucial role in various geophysical processes, including dissipation of wave energy and atmospheric gas exchange. Improved understanding of breaking waves will enhance our ability to predict gas exchange and defend against risks for coastal communities. A prototype scale experiment was conducted in the GWK wave flume (Hannover, Germany) to measure and monitor coastal erosion caused by wave interactions with the beach with a cross-section of 5x7 m and over 300 m in length. A combination of underwater sonar and above-water lidar systems were used to estimate the cross-sections of waves as they broke onto the shore. We have quantified the migration of the entrained cavity and bubble plume as they appear in the water column—penetrating toward the seabed, moving onshore with the passage of the wave crest, and then rising as it is slowly advected offshore. We have also estimated the overall composition of the splash, cavity, and plume as the breaking wave evolves over time.

1000 – 1015 Low Energy, Passive Acoustic Sensing for Wireless Underwater Monitoring Networks. **Gavin Lowes – Newcastle University** Jeffrey A. Neasham, Richie Burnett and Charalampos C. Tsimenidis

This paper presents work towards developing a low-power, low-cost underwater passive acoustic monitoring network. The main aim is to accurately detect passing vessels by exploiting the acoustic signature emitted during propeller cavitation. To achieve this a novel combination of analogue signal processing and embedded programming has been created. The vessel detection system has been integrated with a very low power piece of hardware, developed by Newcastle University, capable of underwater acoustic communication. The vessel detector is based on the principles of the Detection of Envelope Modulation on Noise (DEMON) algorithm [1]. Using this method, along with statistical standard error of the estimate analysis, decisions are made as to whether or not a vessel is present. These decisions are then transmitted acoustically via an underwater wireless network to the end user. In field trials carried out, the system demonstrated the ability to both detect vessels and communicate results reliably whilst maintaining the low-power, low-cost ethos of this project. Future research is planned to utilise the low-power vessel detection system developed to trigger a higher power mode. This mode will sample the raw audio as opposed to the current method which samples only the signal's envelope. This will allow for a full spectral analysis of the vessel's signature enabling feature extraction and individual vessel characterisation.

1015 – 1030 Mechanical scanning image sonar.
Chris Moorhead – Aberdeen University

I am working with a small company in Aberdeen (SonaVision) who manufacture mechanical scanning image sonar. We are investigating the potential in target detection and identification (ATR) using this form of sonar. During the course of our research, we will be focussing mainly on deep learning techniques of detection and identification. By necessity, we will be dedicating a portion to data generation as a means to augment datasets gathered by our own device in both a lab and natural environment. We will also investigate the best methods of applying transfer learning – namely using images from other sonar devices and synthetic data to improve performance in our own domain.

1030 – 1100 Tea and coffee

Session 2 Session Chair – Dr Philippe Blondel (University of Bath)

1100 – 1115 Passive Acoustic Monitoring using a Towed Array from a Wave-propelled USV.

Alfie Treloar - University of Bath, Alan Hunter

Jan Bujalka, Roy Wyatt – Seiche Ltd

The use of towed hydrophone arrays deployed from wave-propelled autonomous surface vehicles presents a unique opportunity for long-duration, wide-area passive acoustic underwater surveillance. Example applications include marine mammal monitoring for environmental surveys and mitigation zone enforcement, as well as anti-submarine warfare. These vessels present certain challenges for robust direction-of-arrival estimation using beamforming. The limited propulsion power compared to traditional tow-vessels imposes the constraint of a short array and a shallow tow depth. Moreover, the intermittent nature of propulsion inherent to these platforms exacerbates the problem of uncertainty in the array profile. Uncompensated array curvature causes beamforming errors, which can lead to inaccurate bearing estimates, misdetections, and false alarms.

Data from the Unmanned Warrior '16 trial has been used to investigate these challenges and explore potential techniques for improvement. During the trial, multiple tonal signals were emitted from a SAAB autonomous underwater vehicle. At the same time, an Autonaut unmanned surface vehicle (USV) towing a Seiche Digital Thin Line Array was used to measure the acoustic emissions from this source.

We will present results from beamforming techniques applied to these acoustic data. Methods for estimating the array profile and compensating for these uncertainties will be explored, including a recursive Bayesian estimator, and their applicability and effectiveness will be assessed using simulation and application on the experimental data.

1115 – 1130 Detecting Weak Signals in Highly Impulsive Noise.

Dr Julian Deeks - University of Southampton and Dstl, Paul White and Gary Heald

Detecting a weak sinusoidal signal additively mixed with strong and highly impulsive noise is a problem in real underwater acoustic detection systems such as sonar, it is hard to detect a single tone acoustic transmission when it is masked by the morning chorus of a colony of snapping-shrimp. The problem can be characterised as; the detection performance reduces as the signal power to impulsive noise power ratio reduces, and different detection signal processing techniques all attempt to reduce or otherwise mitigate this deterioration in performance. Although there is a wide variety of newer algorithmic techniques, the commonest approaches for real sonar systems tend to employ long standing 'signal separation' techniques such as Fourier transforms or matched filtering using a replica assumed to be identical to the signal. In both these cases the detector is a binary decision effected by applying a threshold on the separation processing output. These largely linear approaches might be improved if it were possible to usefully exploit some of the nonlinear signal separation behaviours that might exist in system models such as the Lorenz system, Navier-Stokes, Logistic Model and the Duffing system. All exhibit nonlinear behaviours and some can be cast as nonlinear/chaotic stochastic models, which require numerical rather than analytic solution. Generally they were first developed to model the real world; weather cells, turbulent flow, population dynamics and nonlinear electrical circuits respectively. Here we will describe, quantify and compare the detection performance of a conventional replica correlator and binary decider, with and without a nonlinear pre-processing stage based on the Duffing system. An apparently significant improvement in detection performance has been found at the all-important low false positives rates, for the highly impulsive noise case. The second part of this presentation will offer some hopefully useful insights into how to mitigate some of the significant challenges that might be encountered when studying for a PhD part time. The relative emphasis on the elements of the study regime (hours per week, reporting, planning your research, keeping employers happy, telling the story, staying focused, managing your supervisor etc.) are discussed and approaches offered, including "How to avoid having too much fun in rabbit holes!".

1130 – 1145 A Pulsed Power Driven Transient Underwater Pressure Source.

Jessica Stobbs – Loughborough University, B.M. Novac and P. Senior

A pulsed power facility for studying the physics and technology related to generation of transient underwater pressure impulses through electrical discharges is now operational at Loughborough University. A fast HV pulsed power generator is connected to electrodes immersed in a small size freshwater tank. Diagnostic equipment includes voltage and current sensors and, in order to capture the broadband frequency spectrum generated by the source, a pair of high-quality hydrophones covering the pressure pulse spectrum between 1 kHz and 30 MHz. Finally, an ultrahigh speed camera is used to investigate the dynamics of the transient plasma column that forms between the electrodes. The main results, obtained during the most recent study, will be presented.

1145 – 1200 Very Low Frequency Ocean Acoustic Processes.
Shaula Garribo – University of Bath, Philippe Blondel, Alan Hunter

Gary Heald, Duncan Williams – Dstl

Ross Heyburn – AWE

The oceans are acoustically complex and variable, with increasing human activity (e.g. shipping) and decreasing biodiversity, amplified by climate change. The long-range propagation of low-frequency waves makes them ideal to monitor far-away processes and detect individual events. I am starting my PhD using data from the Lofoten-Vesterålen (LoVe) cabled ocean observatory in Norway. The European Marine Strategy Framework Directive recommends the use of 63- and 125-Hz third-octave bands to monitor shipping noise, and my analyses span the frequency range [10 Hz – 125 Hz]. Sound Pressure Levels and third-octave bands are compared between seasons, and we can monitor shipping, detect fin whales, identify earthquakes and assess overall variations with time, from sunrise/sunset to tidal and seasonal scales.

1200 – 1230 **(Invites)** The PhD Process
Professor Cathryn Mitchell - Academic Director of the Doctoral College, University of Bath

<u>1230 – 1330 Lunch (+ group photo)</u>

Session 3 Session Chair – Dr Duncan Williams (Dstl and Imperial College London)

1330 – 1400 Making a Career in Underwater Acoustics - Challenges & Opportunities.
Professor Gary Heald - Dstl and Heriot Watt University

1400 – 1415 Autonomous Underwater Gliders for Passive Acoustic Monitoring of the Oceanic Environment.

Pierre Cauchy - University of East Anglia, K.J.Heywood, B.Y. Queste, N.D. Merchant, D. Risch and P. Testor

Underwater gliders are long-range autonomous platforms. They collect multidisciplinary oceanic data profiles at high spatiotemporal resolution along a predefined path. They offer persistent presence at sea, covering thousands of kilometres over 1 to 6 months with reduced costs and risks, they collect sound velocity profiles and are able to carry various payload. Their unique way of moving unpropelled through the water column makes them extremely quiet compared to other underwater platforms and therefore highly suitable for passive acoustic monitoring (PAM) applications.

We have been deploying PAM gliders for many years, recording underwater ambient noise during months-long missions to monitor the environment. Analysis of the oceanic soundscape allows us to measure surface wind speed, monitor marine life and detect human activities.

Going further, we now focus on rainfall rate, ice sounds and fish choruses. We investigate the challenges to calibrated sound level measurements from gliders, for application to source ranging and assessment of noise pollution.

1415 – 1430 Coupled Scholte Modes in "Soft" Elastic Plates Underwater.

Beth Staples – University of Exeter, A. P. Hibbins, and J. R. Sambles

The Scholte mode is a localised, trapped surface acoustic wave that exists at the boundary between a fluid and a solid. It evanescently decays away from the interface, and propagates along it with a velocity that is less than the bulk speeds of sound in both the fluid and the solid[1]. In a thin plate, the surface waves that exist on each interface can couple to form a symmetric and antisymmetric pair[2].

For "metal-fluid", or hard-solid interfaces, the Scholte phase velocity is approximately equal to the speed of sound in the fluid. This is because the speed of sound in the fluid is less than both bulk speeds of sound in the metal[3]. In this case, the energy of the Scholte wave is largely localised within the fluid, and its character is dictated primarily by the fluid properties. Because of this previous studies, which explored the modes of metal plates underwater, have examined only the antisymmetric coupled Scholte mode. Since for a 'hard' solid the symmetric coupled Scholte is almost non-dispersive and almost sits on the water sound line at all frequencies some studies neglect its existence entirely[4]. This has unfortunately been then taken as a general property of the Scholte mode in numerous studies, rather than being exclusive to 'hard' solid-water interfaces. This present study examines "plastic-solid", or 'soft' solid-water interfaces. For 'soft' solids, the transverse speed of sound is less than the speed of sound in the surrounding fluid. This results in the velocity of the Scholte interface wave being notably less than the speed of sound in the liquid with much of the energy of the Scholte wave now localised within the 'soft' solid[5]. Under these conditions, the symmetric coupled Scholte exhibits dispersive behaviour, and deviates from the Scholte velocity at low frequencies. This behaviour is demonstrated, and experimentally verified using Acrylic plates underwater.

[1] J. G. Scholte, The range and existence of Rayleigh and Stoneley waves, Mon. Not. Roy. Astron. Soc. Geophys. Suppl. **5**, 120, (1947).

[2] M. F. Osborne and S. D. Hart, Transmission, reflection, and guiding of an exponential pulse by a steel plate in water. i. Theory, J. Acoust. Soc. Am. **17**, 1 (1945).

[3] C. Glorieux, On the character of acoustic waves at the interface between hard and soft solids and liquids, J. Acoust. Soc. Am. **110**, 1299 (2002).

[4] F. B. Cegla, Material property measurement using the quasi-Scholte mode. A waveguide sensor. J. Acoust. Soc. Am. **117**, 1098 (2005).

[5] S. N. Guzhev, Study of phase velocity and energy distribution of stoneley waves at a solid-liquid interface, J. Acoust. Soc. Am. **95**, 661 (1994).

1430 – 1445 The d36 Mode for Underwater Acoustics
Hannah Rose – University of Glasgow and Thales UK

The d_{36} face shear mode of vibration associated with anisotropic piezocrystal material holds great promise for future Sonar and medical applications, presenting improved electrical, mechanical and piezoelectric properties. Harnessing this unusual active mode results in enhanced transducer performance, with the potential to meet increasingly demanding customer requirements.

Exploration into using the d_{36} mode has been reported for various applications; however, there remains little published information on how to exploit this novel mode. For example, predicting the trends and dependencies of this novel mode of vibration. The promising opportunities that its utilisation provides also come at the cost of opening a much more complex space for transducer engineers to navigate towards an optimum design. This can hinder the progress and efficiency of the transducer design process.

The purpose of this work is to explore and characterise the d_{36} mode in the context of a simple mechanical system. In this paper, a simple in-air d_{36} mode prototype demonstrator has been designed with finite element analysis (FEA) simulation. It has been built and characterised to give measured results. Laser Doppler vibrometry and modal analysis have been used for the performance measurement and to validate the finite element analysis simulations. The results are compared, discussed and illustrations of this complex mode in action are shown.

1445 – 1500 Using Acoustic Wavefield Coherence to Control Swarms of Marine Robots.
George Rossides – University of Bath, Benjamin Metcalfe, Alan Hunter

Marine robotic swarms have potential application in the tracking of acoustic sources, e.g, marine mammals, seismic events, machinery, intruders, etc. Particle Swarm Optimisation (PSO) is a common algorithm used to control robotic swarms for source localisation. The conventional PSO algorithm makes use of the intensity of a scalar field generated by the source, e.g., the sound pressure level. However, it neglects valuable information contained in the phase of coherent wavefields. Our work has extended the PSO algorithm to also exploit phase information. We consider a swarm of robotic platforms each equipped with a sensor pair so that cross-correlations can be used to measure wavefield coherence and incidence. We have created a new algorithm called coherence/bearing PSO (CB-PSO). Simulations and lab-based experiments using land robots and virtual microphones have demonstrated improved source localisation performance using CB-PSO compared to traditional PSO.

1500 – 1530 Tea and coffee

Session 4 Session Chair – Dr Alan Hunter (University of Bath)

1530 – 1545 In Search of the Elusive Clickers: Experiences of an External Mature Student.
Dr Edward Harland – University of Southampton

During a career in underwater acoustics with the MoD I had frequently encountered a mysterious clicking sound in UK shallow waters. At the time I could not pursue identifying the source of these clicks so suggested this as a research project to a number of people and organisations. Only one person pursued this topic but was unable to identify the source. At the end of my career I decided to take up the challenge to identify the source as a PhD project at ISVR in Southampton University.

Many years before when I had completed my first degree, my employer at the time suggested they would fund my PhD but within months of joining they had changed their policy and no funding was available. As my career progressed there became less chance of finding the time for further studies. It was only at the end of my formal career that I had the time and finances to once again look at completing my PhD.

Identifying the source of the clicking looked deceptively simple. However, the literature search found many potential candidates, and very little hard information on the sounds produced by the various species. My project characterised the sound and its variations and to study the geographic and temporal distribution. It then identified a study site where clicking was known to be heard and to use this site to investigate various aspects of the sound which it was hoped would lead to the identification of the species making the sound.

As with all good PhD projects, the final aim of the work to identify the species was not achieved, but a much better understanding of the click field was achieved, and along the way a problem with a localisation algorithm was identified and characterised. A number of non-scientific obstacles were also overcome.

This paper will summarise the results achieved and also discuss the difficulties encountered, both scientific and administrative. Recommendations will be made for anyone contemplating a similar method of study.

1545 – 1600 Synthetic Aperture Sonar for a Low-cost Agile Platform: Preliminary Results
Ciaran Sanford – University of Bath, Alan Hunter

Allan Willcox - Picotech Ltd

Synthetic aperture sonar (SAS) imaging systems are the cutting edge of underwater sensing. They are capable of producing extremely high resolution images independent of range. As SAS is a coherent imaging technique, generation of clear, focused images is highly dependent on precise knowledge of transducer location. Obtaining positional navigation data to within a fraction of the transmitted wavelength is critical. For this reason, conventional platforms carrying SAS hardware are typically large, slow, stable platforms. These systems are non-agile and are limited to following linear or low-curvature paths. Furthermore, a typical system is inherently high cost, owing to the need for high quality sensors, actuators, and navigation equipment. As of yet, lower-cost, agile platforms employing commercial off-the-shelf equipment have not been widely considered.

In this paper, we present preliminary results from our agile SAS system, a Blue Robotics ROV. The platform is capable of independent lateral movement in all directions, allowing for higher path deviation. The system utilises a Picotech FLS40, an off-the-shelf system designed as a sector-scan sonar. This sonar operates at 500kHz, with a 40 degree beamwidth. Pure data-based navigation is demonstrated using the DPCA[1] method. The use of the DPIA[2] method to navigate through high angular motion is also explored.

We have performed experiments with this platform at a swimming pool with a series of close range targets. These include hemispherical metal objects and a patch of imitation seafloor. Synthetic aperture images of these targets will be provided, as well as a comparison with conventional single-ping and side-scan images.

1. Cook, D. A. (2007). Synthetic Aperture Sonar Motion Estimation and Compensation. Masters Thesis.
2. Gough, P. T., & Miller, M. A. (2004). Displaced ping imaging autofocus for a multi-hydrophone SAS. IEE Proceedings - Radar Sonar Navig., 151(3). https://doi.org/10.1049/ip-rsn

1600 – 1615 Multi-User Broadcast Acoustic Positioning System.
Aman Chawla – Newcastle University, Jeffrey Neasham and Charalampos Tsimenidis

This paper describes work to investigate a true multi-user underwater acoustic positioning network based on the continuous broadcast of low power, spread spectrum signals from 3 or more surface nodes synchronised by Global Positioning System (GPS) reception. The ultimate goal is to provide position update rate of at least 1 Hz to any number of underwater receivers, without the requirement for precise clock synchronisation underwater, whilst minimising the peak power of the broadcasts. Simultaneous reception of multiple signals requires Code Division Multiple Access (CDMA) processing gain combined with adaptive cancellation techniques. Results from simulation and initial field experiments demonstrate the feasibility of this approach. The technique used in this paper will offer an approach to more biofriendly acoustic modem devices for use in regions with sensitive fauna and/or increasingly strict environmental controls.

1615 – 1630 **(Invited)** Transitioning from Academia to Industry: A Case Study.
Dr Andrew Mathieson – Thales UK

Andrew Mathieson is an Acoustics Engineer within Maritime Mission Systems of Thales UK. He joined Thales UK during October 2016 after 14 years at the University of Glasgow were he gained MEng and PhD degrees, held teaching positions, and post doctorate positions in the field of power ultrasonics. Since joining Thales UK, he has the lead the development of a number of sonar transducers, pursued the research interests of Thales UK, while also continuing to contribute scientific community.

Andrew will briefly discuss some of the decisions and motivation behind his decision to transition from academia to industry. In addition, he will also provide an overview of some of the challenges associated with transitioning to industry, along with many of the rewards and benefits which can be gained. Lastly, he will discuss some routes which are open to young academics which could facilitate a transition from academia to industry, as well as providing an overview of what key skill sets industry is looking for in new, but highly qualified, recruits.

1630 – 1645 Closing Talk by the Chair of UKAN Special Interest Group in Underwater Acoustics (SIGUA). **Dr Duncan Williams – Dstl and ICL**

PhD Students attending but not presenting:

Joseph Beadle - University of Exeter

Research: 'Exploration of Acoustic Metasurfaces' – Experimentally investigating acoustic surfaces waves supported on acoustic metasurface both in air and underwater.

Ellen White – University of Southampton

Research: Underwater acoustics through machine learning to develop a systematic way of analysing acoustic data in real time for the use in sensors.

Maxwell Edward – ISVR, University of Southampton

Research: Seabed Acoustics for Inversion of Sediment Properties of the Ocean Floor and Sub-bottom.

Sofie Macdonald - University of Edinburgh

Research: Distributed Sensor Networks for Scene Analysis in GPS Denied Environments.

Thomas Hooper – University of Leeds

Research: Investigating and developing piezoelectrics with high voltage coefficients for sonar applications.

Serish Hussain – University of Leeds

Research: Solid-liquid suspension flows are encountered across the nuclear sector, and their characterisation is of great importance to the safe transport of radioactive material.

This project seeks to understand these issues and overcome pipeline transportation problems in two ways – the development of an online acoustic backscatter technique to characterise particle size and concentration online, and the use of polymer additives to modify slurry flow characteristics enabling safe and efficient slurry transport.

Lydia Katsis – University of Southampton

Research: I have just started my PhD in the Department of Geography at the University of Southampton. My PhD is looking exploitation of wildlife in tropical forests, in particular hunting. The overall aim is to provide evidence to inform conservation management in neotropical forests. I will be using AudioMoth acoustic sensors to detect gunshots and quantify hunting and explore spatio-temporal hunting patterns in a protected area. I will complement this data with social surveys of hunting communities and camera trapping of the prey base.