IQOE Workshop on Low-Cost, Self-contained Underwater Acoustic Recording Systems

13-14 December 2021

Meeting Website: https://www.iqoe.org/workshops/iqoe-workshop-low-cost-self-contained-underwater-acoustic-recording-systems

Monday 13 Dec., 16:00-18:00 UTC	Chair: Peter Tyack Host: Ed Urban	Meeting Link: https://us06web.zoom.us/j/85667512547?pwd=M01JRTZCZTJ0Z3BTall2czdoc3JFQT09 Meeting ID: 856 6751 2547 Passcode: 820497
Tuesday 14 Dec., 01:00-03:00 UTC	Chair: Peter Tyack Host: Ed Urban	Meeting Link: https://us06web.zoom.us/j/83905633314?pwd=MGpsQW4xaGVCaTh4ZEJ2M01nN0g5UT09 Meeting ID: 839 0563 3314 Passcode: 583995
Tuesday 14 Dec., 09:00-11:00 UTC	Chair: Lucille Chapuis Host: Sophie Seeyave	Meeting Link: https://us02web.zoom.us/j/88156466821?pwd=T2dVTXJWaG0yb3kxSENnYWc0dUcvdz09 Meeting ID: 881 5646 6821 Passcode: 425898

Agenda (will be repeated for each of the three sessions)

Introduction to Workshop – Session Chair

Submitted presentations (full author lists and affiliations are given on the abstracts) (30 min.)

1. Calibration of Digital Hydrophones – Jay Abel (Sensor Technology Canada)
2. Real-time and low-cost passive acoustic monitoring – the CORMA experience – Paolo Diviacco et al. (National Institute of Oceanography and Applied Geophysics - OGS, Italy)
3. HydroMoth: testing a prototype low-cost acoustic recorder for aquatic environments - Timothy Gordon et al.
4. Observation of the anthropogenic sound in the Persian Gulf – Maziar Khosravi (Iranian National Institute for Oceanography and Atmospheric Sciences (INIOAS))
5. Observations of acoustic fluctuations on the inner continental shelf in Central California – Kaus Raghukumar (Integral Consulting Inc.)
6. Low-cost Ocean Acoustic Observations based on the AI-based Framework for Acoustic Sensors (AFAS) – James Theriault et al. (Ocean Environmental Consulting, Canada)
7. Orcasound's lowest-cost open source live-streaming PAM solution on a Raspberry Pi – Scott Veirs (Orcasound)
8. Autonomous computationally efficient power spectral density estimation using performance-weighted blending – Kathleen E. Wage et al. (George Mason University)
9. In Situ Measurement of Rain Rate and Wind Speed Using Underwater Ambient Sound Over Global Oceans – Jie Yang, Stephen C. Riser, and Jeffrey A. Nystuen (Applied Physics Laboratory, University of Washington)

Discussion Topics

1. How close are we to having low-cost self-contained underwater acoustic recording systems for measurement of ambient sound that fulfil the following requirements:
   a. Easy to use for education and citizen science, but not necessarily for research. What role can citizen science play in democratising and globalising acoustic measurements? (30 min.)
   b. Cheapest calibratable, stable hydrophone that can be adapted to GOOS-relevant platforms. Can we develop a global project to deploy such technologies worldwide, that produce FAIR data, and will contribute to the implementation of the Ocean Sound EOV? What training programmes and resources would be required to support students, early-career and developing country scientists? (40 min.)
2. What are the next steps required to make this a reality? (20 min.)

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Title: Calibration of Digital Hydropones

Presented by: Jay Abel, Sensor Technology Canada

Keywords: Calibration, Reciprocity, Digital, Transducer

Calibration by reciprocity allows primary calibrations without using a standard reference. For analog hydrophones, the procedure requires a tank, tone source, projector, data acquisition system, and processing, and requires three devices, at least one of which being able to operate as a transducer (first as a projector, then as a hydrophone). Normally, amplified hydrophones and digital hydrophones cannot be used as a transducer because the preamp and other electronics restrict the use of the device to receive only.

With some additional complexity, the preamp can be combined with a low power projector amplifier, and the preamp channel can be switched to measure projector current. The result is a digital transceiver that either records the voltage across the ceramic element in hydrophone (receive) mode, and records the current through the ceramic element in projector (transmit) mode. This composite device can be used with two other devices to implement a reciprocity calibration by analysis of the recorded receive voltages and transmit currents.

While the power available for the projector function is too low to use the device as a general purpose projector, the available power is sufficient to allow calibration to take place.

Real-time and low-cost passive acoustic monitoring – the CORMA experience

Paolo Diviacco [1],* , Antonio Nadali [2], Massimiliano Iurcev [1], Mihai Burca [1] , Rodrigo Carbajales [1] ,Matteo Gangale [2], Alessandro Busato [1], Fabio Brunetti [1], Lorenzo Grio [2], Alberto Viola [1] and Nikolas Potleca [1]

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Keywords: Passive acoustic monitoring; real-time; low-cost; web; scalable infrastructure.

Within the CORMA project a real-time and low-cost Passive Acoustic Monitoring (PAM) system has been developed that is able to record and transmit data to a central server where they can be automatically processed and published on a web platform (Diviacco et al., 2021). The system is based on off-the-shelf and low-cost technologies combined with a scalable infrastructure developed with open-source tools only, which allows great flexibility in extending what developed so far. In fact, although currently the system has been tailored and successfully tested to fit mainly the needs of shallow coastal areas it can be redesigned to match the needs of other environments. The hydrophone is deployed at sea and connected through a 100 meters long shielded cable to the acquisition box installed on a buoy. The box is composed of an analog to digital converter with a frequency range 20-20.000 Hz, a Raspberry Pi board and a transmission system. This latter is currently based on 3G/4G GSM mobile telephone networks which of course have a limited range of distances between antennas but that has a proper bandwidth that allows the device to send data packets with the correct schedule. We are currently working on extending the types of data transmission technologies in order to extend the range of distances from the coast of the listening points. Electric power is provided by solar panels installed on the buoy. The low-cost characteristic of the system allows for the deployment of multiple units at the same time without exploding the budget. This allows to monitor larger areas or the same area with a denser network of observation points, which is particularly important while integrating monitoring and modelling. The real-time monitoring characteristic can be particularly relevant in identifying anomalous events and try to warn or mitigate their effects in particular in the vicinities of marine protected areas. We installed a small network of listening points in the Gulf of Trieste (North Adriatic Sea) and acquired a large dataset of recordings. These can be accessed through the project websites while each recording provides on the fly data products such as spectrum, spectrogram, and time dependent sound pressure level.

Reference: Diviacco et al. (2021), JMSE, 9 (4), 390, DOI: 10.3390/jmse9040390

HydroMoth: testing a prototype low-cost acoustic recorder for aquatic environments

Timothy A. C. Gordon*, Lucille Chapuis*, Benjamin Williams, Sasha Dines, Tess Gridley, Guilherme Frainer, Jack Fearey, Permas B. Maulana, Mochyudho E. Prasetya, Jamaluddun Jompa, David J. Smith, Stephen D. Simpson
* authors contributed equally

Keywords: hydrophone, audiomoth, low-cost recorder, passive acoustic monitoring

We test a prototype low-cost, low-specification aquatic recorder called 'HydroMoth'. This device is a modified version of the widely used terrestrial recorder (AudioMoth), altered to include a waterproof case and customisable gain settings suitable for a range of aquatic applications. We test the performance of the HydroMoth in both aquaria and field conditions, recording artificial and natural sounds, and comparing outputs with identical recordings taken with commercially available hydrophones. Although the signal-to-noise ratio and the recording quality of HydroMoths are lower than commercially available hydrophones, the recordings with HydroMoths still allow for the identification of different fish and marine mammal species, as well as the calculation of ecoacoustic indices for ecosystem monitoring. Finally, we outline the potential applications of these low-cost, low-specification underwater sound recorders for bioacoustic studies, discuss their likely limitations, and present important considerations of which users should be aware.

Observation of the anthropogenic sound in the Persian Gulf

Maziar Khosravi, Iranian National Institute for Oceanography and Atmospheric Sciences (INIOAS)

The oceanic region comprised of the Persian Gulf, Strait of Hormuz, and Gulf of Oman is an important military, political region, and one of the most heavily traveled waterways in the world. Approximately 65% of the world's marine transport of oil belong to Persian Gulf littoral countries. Persian Gulf (PG), as a shallow marginal sea, lies between the Arabian Peninsula and southwestern Iran. Besides, the PG is biologically of interest for its unique biodiversity (e.g. jellyfish, corals, anemones, sea star, sea cucumber, oysters, fishes, dolphins, sea turtles, dugongs, birds, crabs and many other species even whales and whale sharks).

In view of the above, due to high volume of human activities (e.g. commercial shipping, seismic surveys, oil exploration, and military sonar), the PG region potentially is one of the most adversely affected marine environments worldwide under impacts of anthropogenic sound. However, owning to the dearth of the sound data, the current and future effects of sound-generating activities on marine life in this area is unknown. To the best of the author's knowledge, there is no previous study to investigate the changes in the behavior of marine animals under special effects of the anthropogenic sound in the PG. Sound-generating activities causes stress and drives the animal out of its habitat. Furthermore, it seriously can reduce an animal’s ability to communicate, navigate, locate prey, avoid predators, and find mates.

In conclusion, considering the fact that, I am an observational oceanographer at INIOAS, with a particular expertise in field measurements and instrumentation, and also taking the advantages of oceanographic equipment of INIOAS, I strongly suggest observing sound to promote observation of the key biological and physical variables at several sites in the PG region, where temporal and spatial sound data do not already exist. There is a strong capability to conduct the field measurements and completing this project as a part of global observation of sound particularly under the author's direct supervision.

Keywords: Persian Gulf, Anthropogenic Sound

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Title: Observations of acoustic fluctuations on the inner continental shelf in Central California

Abstract: The recently completed Inner Shelf Direct Research Initiative (IS-DRI) experiment examined in great detail the physical oceanographic processes involved in the exchange of heat and momentum from outside the surf zone to the inner continental shelf, with a focus on features such as rip currents, fronts, and nonlinear internal waves. During this experiment, a low cost 27 kHz source was utilized, along with multiple self-contained underwater acoustic recording systems, with the goal of understanding nearshore acoustic fluctuations and their impact on acoustic communications and sonar performance. Acoustic intensity fluctuations are examined during two week-long periods during which intensity fades greater than 20 dB were observed. Variability spectra were found to be dominated at lower frequencies by tidal oscillations and higher frequency variability is attributed to intense nonlinear internal wave activity. Ambient noise spectra were found to be anisotropic, with low frequency spectral levels dominated by noise from wave breaking. When significant wave heights exceeded 3 m, a significant drop in spectral levels is observed, likely due to attenuation of sound by bubble plumes from breaking waves which are then ejected offshore by rip currents. Images from airplane flight missions confirmed the presence of offshore bubble plumes during swell events.

Low-cost Ocean Acoustic Observations based on the AI-based Framework for Acoustic Sensors (AFAS)

Theriault, James A.[1]; Flogeras,David[1]; Frazao,Fabio[2]; Kirsebom, Oliver S.[2]; Padovese, Bruno [2] and Matwin, Stan [2]

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The AI-based Framework for Acoustic Sensors (AFAS) has been developed and prototyped as an extensible architecture. The framework is intended to be constructed at a low cost, but have significant self-contained processing capability. The current prototype has been specifically designed to allow modular hardware and software components for testing, profiling, and optimization. For example, the integrated system enables the testing and efficiency profiling of deployed North Atlantic Right Whale classification models generated by the MERIDIAN KETOS neural-network classification package. The design also allows the deployment of the MERIDIAN MARNOISE soundscape metrics package (which is being developed in parallel to ISO 7605 Standard: Measurement of Ambient Underwater Sound development). In its most basic form, AFAS consists of a hydrophone, analogue-to-digital converter, and data capture system. The first prototype consisted of the most basic form using a mixture of off-the-shelf and custom supplier and was specifically designed for application in a low-cost ocean profiling buoy. The current enhanced prototype has relied on primarily off-the-shelf components, with only the power control board being a custom board. Even the pressure cases use the Open ROV standards that allows the components to be obtained from multiple sources. Though the effort is generating a low-cost design, further cost reductions can be achieved but at a performance price. Dynamic range, frequency range, self-noise, operating depth, and deployment life can be sacrificed in order to reduce the overall production cost. Future evolutions will likely see a further balancing of the off-the-shelf versus custom components in order to reduce cost and build complexity. Decisions on performance sacrifices will occur after further testing of the current build. Integral to the project is the enhancement of a broadband projector system used for testing and calibration.

Abstract draft:

Title:

Orcasound's lowest-cost open source live-streaming PAM solution on a Raspberry Pi

Names & affiliations:

Presenter and co-author order tentative/TBD, could vary depending on who is available/interested and/or by date-time workshop, too…

Scott Veirs, Orcasound
Val Veirs, Orcasound
Steve Hicks, Orcasound
Paul Cretu, Orcasound
Joyce Liao, Orcasound

Keywords:

Real-time, Raspberry Pi, killer whale, cabled

Abstract:

For about 20 years, the Orcasound hydrophone network has monitored the habitat of endangered Southern Resident killer whales (SRKWs) in Washington State, USA. Because these salmon-seeking orcas emit many types of signals that humans can hear (<15kHz), for real-time detection of SRKWs Orcasound nodes can be put into listening-only mode and use very inexpensive hardware: a single-board computer and a USB-based ADC that cost <$100 U.S. In contrast, the least-expensive hydrophones that are durable enough for these year-round near-shore cabled deployments cost $300-600 U.S. per element. Depending on the deployment method, these hydrophones have lasted for 3-5 years, so their per/year cost is tolerable. Nevertheless, we are looking for ways to drive the initial cost of our hydrophones down to <$100. In 2018 we deployed Raspberry Pi computers with the Pisound HAT (2 channel, 24 bit, 192kHz) and have been extremely satisfied with their durability (no failures after ~2 years in 3-5 locations). Our open-source software is free and our on-going cloud-based storage/streaming costs are about $10 per month per node. We would welcome additional deployments of our solution for monitoring noise at other "docks of convenience" where power and Internet access are available and a short cable run can reach water depths of ~5 m-10 meters. We also are interested in open source code contributions via github.com/orcasound, including possible modification of our code and open machine learning algorithms for edge computing or autonomous recorders. Our focus has been on optimizing real-time performance for both human

and machine detection and classification, but a goal for 2022 is to improve how we measure and monitor ambient noise and ship levels, using calibrated and/or relative noise metrics.

Autonomous computationally efficient power spectral density estimation using performance-weighted blending

Kathleen E. Wage (George Mason University)
Jeff Tucker (George Mason University)
John R. Buck (University of Massachusetts Dartmouth)
Lora J. Van Uffelen (University of Rhode Island)

Keywords: power spectral density estimation

Calibrated power spectral densities (PSDs) provide important information about the frequency content of natural and anthropogenic sources of ocean ambient sound. The classic Welch method (IEEE Trans. Audio Electroacoust., 1967) computes PSD estimates by averaging windowed Fourier transforms of the data. The choice of window controls the estimators frequency resolution and its ability to isolate loud signals within a band, enabling quiet signals in other frequency bands to be measured. Choosing an appropriate window typically requires knowledge of the dynamic range and variability of signals in the environment. Since this information is not generally available prior to deployment, signal processing analysts typically tune the window parameters once data becomes available, and adjust them whenever the environment changes significantly. This talk describes a novel approach to power spectral density estimation that computes a PSD estimate as a weighted blend of an ensemble of Welch estimators. The estimators in the ensemble are based on a set of windows that provide different tradeoffs between resolution and interference rejection. The Performance Weighted Blended (PWB) estimator automates the work of a skilled signal processing analyst and adapts to find the best estimate in each frequency band. In addition it can be implemented efficiently since it is based on a small set of conventional spectral estimators that use Fast Fourier Transforms. This talk summarizes the PWB approach to spectral estimation and illustrates its performance using data from a hydrophone mounted on an underwater glider.
[Work supported by ONR]

In Situ Measurement of Rain Rate and Wind Speed Using Underwater Ambient Sound Over Global Oceans

Jie Yang, Stephen C. Riser, and Jeffrey A. Nystuen

Knowledge of the intensity and spatial-temporal distribution of rainfall over the ocean is critical in understanding the global hydrological cycle. However, rain has proven difficult to measure over the ocean due to problems associated with platform motion and flow distortion combined with the spatial and temporal variability of rainfall itself. Underwater acoustical rain gauges avoid these issues by using the loud and distinctive underwater sound generated by raindrops on the ocean surface to detect and quantify rainfall. Here, the physics, operation, and results from the Passive Aquatic Listener (PAL) instrument that uses underwater ambient sound to measure rainfall rate and wind speed are presented. Since 2004, more than 80 PALs have been deployed on Argo profiling floats, each with 3-4 years of residence time. This talk focuses on PAL data from the two NASA-sponsored field experiments in the northern Atlantic and eastern tropical Pacific oceans. The PALs provide near-continuous measurements of rain rate and wind speed over the two field study regions defined by the Argo profilers. Comparisons of the PAL data with rain and wind measured by other techniques including direct measurements show good agreement for both rain rate and wind speed.