EMPIR JOINT RESEARCH PROJECT

May 2022

INFRAAUV News

NEWSLETTER NUMBER 2

CONTENTS

WELCOME

Eighteen months of project research and development have past and the Infra-AUV project starts its second half. In the meanwhile a lot of the expected progress has materialised and of course some unexpected findings brought new experience and knowledge, too. We are pleased to present our second newsletter in order to provide the latest news to you, our stakeholders.

As you may remember from our first issue the project involves a lot of calibration systems development and optimization for calibration devices. Most of this work, at least for infrasound (the "A") and vibration (the "V") is successfully completed by now and you will find some reports of the novel devices that now exist on the subsequent pages.

In metrology, a commissioned or significantly changed device always calls for the comparison between peers to demonstrate and validate performance. Accordingly, several inter-laboratory comparisons are currently planned for the new primary and secondary calibration methods.

These methods then establish the root of traceability for the sensors deployed at monitoring stations.

Hence, the validation of our efforts in the laboratory will be the cornerstone for the successful on-site calibration of the deployed sensors.

While the tension rises for the metrologists in our team, the geoscience and monitoring station experts are busy preparing the stage for their grand finale.

On this account studies have been performed on the potentially exploitable on-site excitation sources to determine which of these signals are viable as calibration stimuli.

The dependency of on-site sensor systems on environmental conditions and the feasibility of existing on-site calibration methods are also the subject of our research activities.

Finally, in a first use-case, environmental infrasound measurements with calibrated sensors have been performed successfully and are now published, providing new insight, and confidence that the project is still on the right track.

We hope you find the news as exciting as we found the research. As always you can find out more via our web-site or by direct contact to our Team.

- Thomas Bruns, project co-ordinator

THE CONSORTIUM

This consortium brings together a wide range of expertise and leading skills found within the partner organisations and comprises national metrology institutes (NMIs) and designated institutes (DIs) who are complemented by a number of research institutes and IMS station operators representing the expertise needed from the stakeholders.

PTB, Germany
HBK, Denmark
CNAM, France
DFM, Denmark
LNE, France
NPL, United Kingdom
TUBITAK, Turkey
BGR, Germany
CEA, France
ASN, United Kingdom

NEWS IN BRIEF

INTERCOMPARISON OF SEISMOMETER CALIBRATION

One project goal is the development of on-site methods for seismic sensor calibration, requiring suitable devices to be specified for transferring traceability from the laboratory to the field. Potential commercially-available seismometer models were therefore assessed from their technical specifications, and three candidate devices have been identified: Geotech Instruments GS-13 (a uni-axial device operating in the horizontal plane), Streckeisen STS 2.5 and Nanometrics Trillium 360 GSN (both 3-component seismometers). These devices will now be assessed for stability, transportability, operating frequency range, and general usability, within an inter-laboratory comparison involving three project partners (HBK, CEA and PTB). The intercomparison will also provide the first performance evaluation of the new calibration facilities developed by each partner.

WIND-NOISE REDUCTION SYSTEMS AND THE IMPACT OF DEFECTS

The WNRS is a vital component of an infrasound station. It reduces the noise associated with wind-generated turbulence, without greatly impacting the observed infrasound signals. Models have been developed to describe the response of these systems, but there are no studies describing the effects of system defects (e.g. blocked pipes).

During this study, the models have been extended to include various defects, and experiments using a temporary WNRS associated with the MB3 microbarometer have been performed to provide experimental WNRS responses. The initial analysis demonstrates synergy between the model and the calibration data for a scenario with 8 blocked inlets.

SECONDARY CALIBRATION OF HYDROPHONES

Secondary calibration of hydrophones uses the same principles adopted for microphones, where the device under test is compared with a reference sensor when both are subjected to the same sound pressure, applied simultaneously or sequentially. While it is reasonable to expect this calibration to be carried out in water, this is in fact not essential, as hydrophones effectively have the same sensitivity in air as in water (for the same environmental conditions). Calibration in air opens the possibility for the reference sensor to be either another hydrophone or a microphone, provided it can itself be calibrated by some other means. This usually means that a reference microphone is chosen, and traceability for the hydrophone calibration is to measurement standards for airborne sound.

The project is now aiming to resolve this incongruity, with both NPL and TUBITAK developing primary calibration methods for hydrophones at low frequencies, alongside secondary calibration methods. Both still make use of air-filled chambers for secondary calibration at ambient environmental conditions, but the move to calibrations at simulated ocean conditions will require pressurized water-filled cavities, where a reference *hydrophone* becomes essential. Calibration with such facilities are also under consideration, where the larger wavelength of sound in water compared to air, gives greater flexibility in the design and geometry of the cavity.

CALIBRATION OF MICROBAROMETERS

In the objective to disseminate traceability for airborne acoustics, CEA, LNE and PTB have developed secondary calibration facilities that are now ready to be used. These facilities are based on a comparison method using a reference microphone; currently either B&K type 4160 or B&K type 4193 which is especially suited to low frequency measurement. The new facilities are based on either an active coupler or sound tube (essentially a waveguide driven by a loudspeaker), and operate in the frequency range from 10 mHz to 20 Hz. They were designed to allow the calibration of a large variety of sensors, including microbarometers such as MB2005 and MB3. Microbarometer are commonly used for geophysical field studies and real-time monitoring of events such as explosions, volcanoes, convection etc. The facilities at CEA, LNE and PTB provide new capability for microbarometer calibration with estimated measurement uncertainties of around 0.04 dB at frequencies around 1 Hz and 0.3 dB at frequencies approaching 10 mHz. An interlaboratory comparison across these systems is planned in the next months.

ALIGNMENT WITH CTBTO TECHNOLOGIES

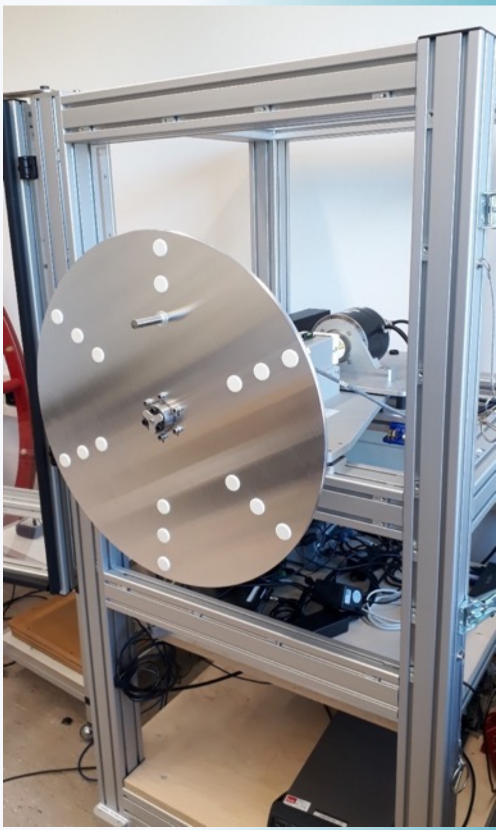
As a key stakeholder, alignment of project developments and goals with the well-established technologies in use at CTBTO, is immensely beneficial. The project team has consulted with CTBTO on several topics, including the selection of infrasound sensors to be used at travelling reference standards, and on potential calibration methods for hydroacoustic systems, where accessibility issues are at an extreme level due to their deep-sea deployment environment. CTBTO also have a well-developed method of on-site calibration for infrasound sensors, and potentially other types of sensors. So rather than work independently, the project team have agreed to develop the metrology aspects of the CTBTO calibration process, with a goal to integrate traceability and measurement uncertainty considerations into the CTBTO software application for on-site calibration. This goal forms the basis of a case study being developed in the project.

RESEARCH HIGHLIGHTS

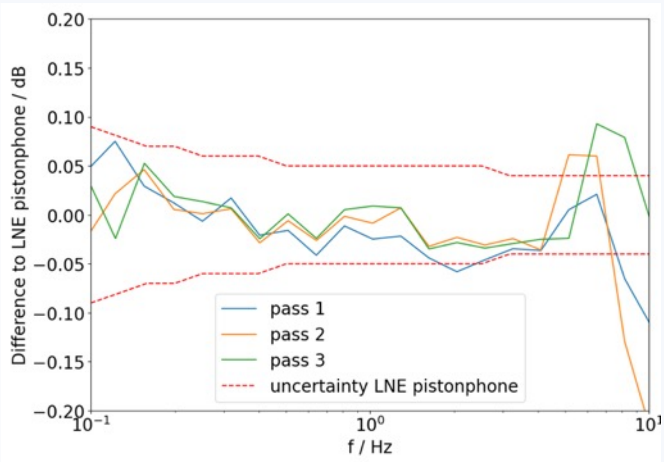
MICROPHONE CALIBRATION BY THE 'CAROUSEL METHOD'

Several absolute calibration methods for microphones and infrasound sensors are under development at different institutes within the project. This offers valuable opportunities for mutual verification and a solid basis for establishing primary measurement standards to support infrasound measurements. A method recently implemented at PTB is based on exploiting the vertical gradient of the ambient pressure. At laboratory conditions this gradient is approximately −11.5 Pa/m, so viable sound pressures are possible with practical changes in height. Calibration where the device under test is subjected to a sinusoidal vertical displacement has been postulated for many years, but recent developments at PTB have produced the world's first system capable of producing high quality results.

The picture shows a half-inch measurement microphone undergoing calibration with the apparatus. The basic element of the setup consists of a disk rotating at a constant speed (from which comes the name 'carousel method'). It is very important for the disk to be accurately positioned in the vertical axis and for the eccentrically mounted device-under-test to undergo a precise and well-characterised circular orbit. The rotational speed of the disk defines the frequency of the excitation signal.



PTB carousel calibrator apparatus for microphone calibration



Difference in microphone sensitivity determined by PTB carousel method and LNE laser pistonphone (baseline).

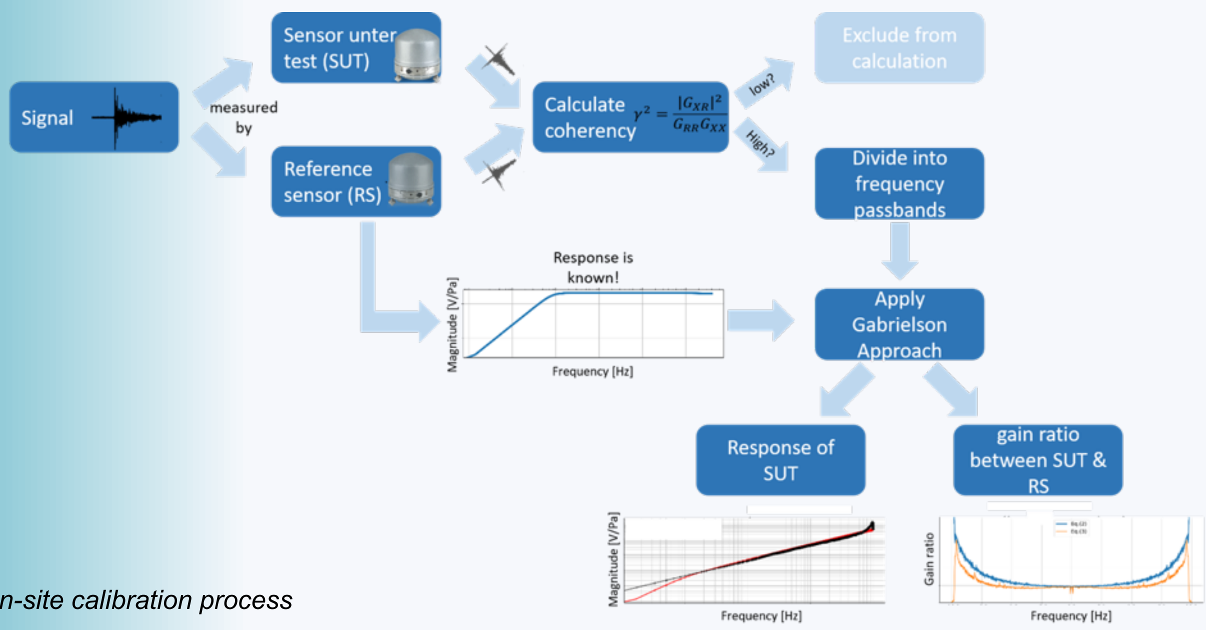
This measurement setup has currently been applied in the frequency range from 0.1 Hz to 10 Hz. Comparisons with a primary calibration conducted in the laser pistonphone developed at LNE (see Newsletter Issue 1) showed a very good agreement for frequencies below 5 Hz, as seen in the graph. Several challenges have been overcome to achieve this level of performance. The most significant of these is the control of wind-induced noise as the microphone passes through the air, which has been achieved with a special 3D-printed nose cone for wind shielding. Further research on the aerodynamics is ongoing and aims to improve performance for frequencies above 5 Hz.

ON-SITE CALIBRATION OF MICROBAROMETERS & SEISMOMETERS

A key task of the Infra-AUV project is the development of specific methods of low-frequency on-site calibrations for maintaining traceability and monitoring the performance of permanently deployed sensors within local, regional and global networks. These could be sensors of any type, but here we consider both infrasound sensors and seismic sensors specifically.

While numerous on-site calibration methods for seismometers have been developed to date, they are a variation of the same basic principle; a comparison calibration using a common excitation signal (often an ambient stimulus), determination of the voltage ratio between the devices and derivation of the response of the device under test, from the known response of the reference sensor.

The same approach has been adopted for infrasound sensors, where the output voltage ratio is calculated as a function of frequency using spectral methods but is further complicated by the need for a Wind Noise Reduction System (WNRS) with its distributed pick-up points.



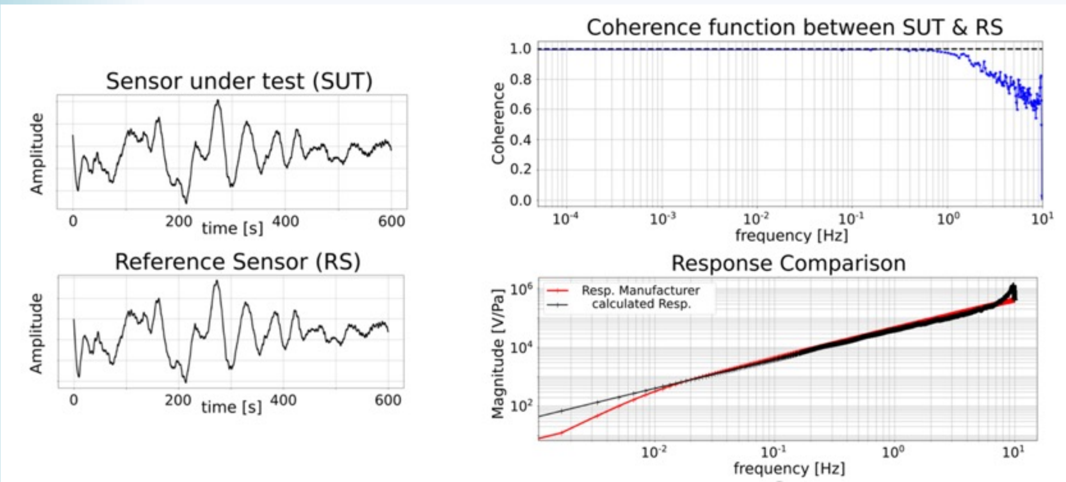
The on-site calibration process

Several assumptions underpin the approach: first, the response of the reference sensor has to be known; second, the sensor under test and the reference sensor measure the same coherent signal; and third, effects of incoherent components can be neglected. Consideration of these assumptions are critical for implementation. In fact both sensors measure a mixture of coherent and incoherent signal, and identifying the coherent component of the signals below 0.1 Hz is challenging. Moreover, wind-generated noise plays a crucial role, especially since the reference sensor lacks a WNRS. Introducing metrics that indicate similarity in the sensor signal select the time periods of high signal coherence for analysis, then conducting the analysis after filtering the data within different passbands, are some of the solutions that have been developed to mitigate departure from the core assumptions.

The process can be seen illustrated above.

A specific implementation of above approach has been applied using the different types of infrasonic stimuli identified in a [soon-to-be-published study] from the project, to assess which of them is best suited to the chosen approach. The influence of different parameters such as signal length and the number and size of the applied time windows during response estimation, have also been investigated to find a suitable combination of these parameters.

So far, this particular approach has only been used with infrasound sensors, but the transferability of the method has been evaluated with data from a range of seismometers models and different types of excitation signal. The work is ongoing, but the initial conclusion is that the method appears to work successfully.



Sample responses with calculated coherence function and resulting sensor response.

This is the first application of this approach to the on-site calibration at seismic stations, thus demonstrating that advantages in complying with underlying assumptions can be transferred to seismometer calibrations.

Future plans including applying the modified approach to on-site calibration of both infrasound and seismometer stations in Germany and France using various natural and anthropogenic seismic and infrasonic excitation signals and a calibrated sensor as a reference.

APPLICATION FOCUS

TRACEABLE MEASUREMENTS OF LOW-FREQUENCY NOISE AND INFRASOUND NEAR A WIND PARK

The expanded use of wind energy as part of the transformation to renewable and sustainable energy production is currently hindered by serious questions concerning the noise emission and the resulting impact on people living in the vicinity of wind parks. In nearly all European countries this question is the topic of a serious and highly emotive debate which should ideally be informed by objective knowledge and proven and reliable quantitative data mainly about current exposure situations. Reliable and traceable measurements of infrasound power levels in the vicinity of a particular emitting source will gain an increasing importance with respect of this purpose and important prerequisites for a successful implementation of such measurements in practice are developed in this project.

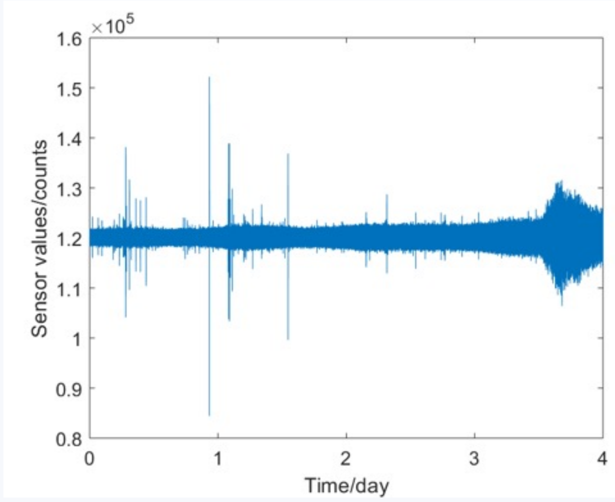
To investigate the levels of infrasound emitted from a typical wind park as a first example, project partners BGR and PTB carried out traceable measurements of infrasound near the wind park Gagel located in Altmärkische Höhe, Saxony Anhalt, Germany. Seven measurement stations equipped with micro-barometers were placed by BGR in increasing distances to the wind park on a ground mainly covered with trees and closed bushes. The stations continuously recorded the infrasound signals in the environment generated by any source. These measurements were accompanied by microphone measurements carried out by PTB at three of the stations (see Figure 1) to compare the results and thus, to investigate properties of both measurement systems. The raw data of the microphone measurements were analysed by a procedure beyond the standardised methods (IEC 61400) to investigate the influence of wind and other environmental events. It could be shown that infrasound can be detected by both measurement techniques and that results can be obtained which agree well within an acceptable and justifiable range. Wind, however, is an important factor and additional strategies are necessary to quantitatively describe its impact on results.

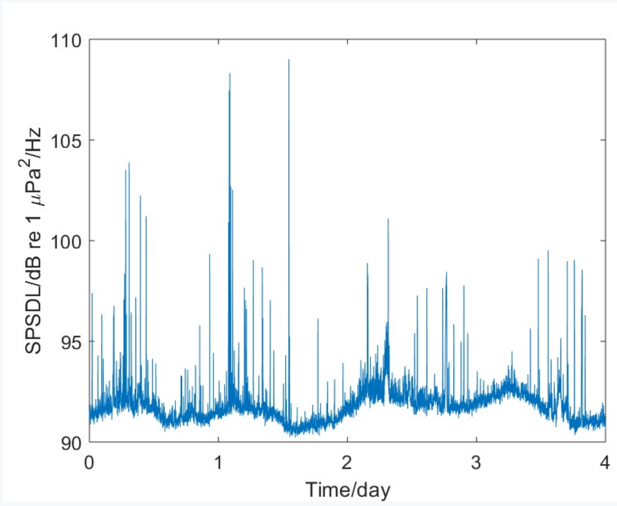
All data, results and reference values for a first estimation of noise impact are publicly available via the PTB Open Access Repository: Here.

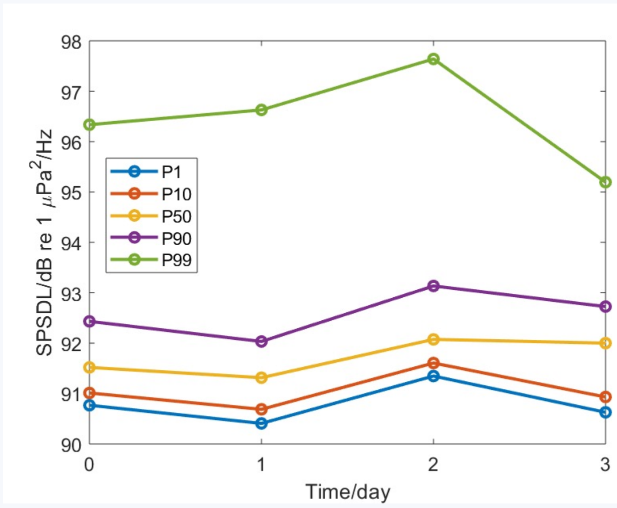
Low frequency noise test measurement at wind park

THE IMPACT OF TRACEABILITY AND UNCERTAINTY PROPAGATION IN THE ASSESSMENT OF OCEAN NOISE

The data recorded by a sensor operating in the field, possibly as part of a deployed sensor network, are used by different end-user communities for different purposes. For example, in the case of underwater acoustic measurement, the data might be used for event detection and attribution to derive temporal, spatial and amplitude information about the event, which can be anthropogenic or natural. Another use might be for ocean noise monitoring in which the data are used to derive metrics for ambient noise maps for a given spatial region and time period, for example, the percentage of time that an exposure threshold for sound pressure level is exceeded. Yet another use might be for environmental monitoring in which the data are used to derive long-term (e.g., decadal) trends in sound pressure level and to correlate characteristics of the recorded sound with natural and anthropogenic sound sources.







The Infra-AUV project is delivering traceable calibration of acoustic, underwater, and seismic sensors for measurements at low frequencies, as well as improved knowledge of their performance in-situ. Various case studies are being used to demonstrate the impact for different end-user communities of that traceability and improved knowledge. Specifically, the project is investigating methods for the propagation of uncertainty, including that associated with the calibration of a sensor, through models for high-level derived parameters related to various end-user applications. Quantifying reliably the uncertainty for estimates of these high-level parameters is essential when those estimates are used for decision-making or to inform policy, as well as to understand the comparability and consistency of estimates relating to different locations and times.

The models involved in such applications are often complicated and computationally intensive. An example related to underwater acoustic measurement is illustrated in the graphs, which show the data at various stages in its processing. The top graph shows the raw digital data (in counts) recorded over four days by a hydrophone in the CTBTBO's International Monitoring System. The middle graph shows values of sound power spectral density level (SPSDL) derived from the raw data using information about the measuring system in terms of a scaling factor (for converting counts to values of sound pressure in pascals) and its calibration provided as a frequency response. Finally, the bottom graph shows percentile values of SPSDL representing summary statistics extracted from the distributions of values taken over each day. These are examples of the high-level metrics of interest, providing information about the overall soundscape that allows end-users to estimate respective contribution of natural and anthropogenic sound sources.

The complexity of the models means that numerical methods, such as a Monte Carlo method, provide a practical approach to undertake the propagation of uncertainty. The advantages of the approach are that it is generally applicable, it does not require the explicit calculation of sensitivity coefficients, and it makes no assumptions about the nature of the model or about the nature of the probability distributions for the derived parameters. However, the disadvantage of the approach, is that it can be computationally expensive.

STAKEHOLDER ENGAGEMENT

LINKING WITH THE GLOBAL STANDARDIZATION COMMUNITY

The Infra-AUV project plans to make several important contributions to standards prepared by the International Organisation for Standardization (ISO) and the International Electrotechnical Commission (IEC) during its lifetime.

In the IEC Technical Committee on Electroacoustics (TC 29), project outputs have already initiated new strategic discussion on infrasound measurement and driven progress on two IEC publications.

The project report compiling performance and test requirements for infrasound measuring instruments was presented to the global electroacoustics community in the TC 29 plenary meeting. It was also given more detail scrutiny in the group of experts on sound level meters, where it was concluded that the IEC 61672-series of international standards should cover this topic and adopt the project outputs, perhaps as a new part of the series. The need for a new type of portable sound calibrator was also highlighted as a potential future need, though this is outside the scope of the current project.

Separately, the working group on measurement microphones progressed a revision to the international standard IEC 61094-2 that describes the realisation of primary measurement standards for airborne sound – a topic at the heart of this project. A newly introduced analytical model formulated by members of the Infra-AUV project team, effectively extends the scope of this standard to infrasound frequencies, including the range from 40 mHz to 10 Hz targeted by this project. The revised standard has now been published and marks an early success in the project's standardisation goals.

A second document on alternative calibration methods suited to infrasound has also been prepared by members of the project consortium. It is pending publication having recently been approved by the international members of TC29, and should appear in the coming months.

Why are standards important?
Quality assurance schemes often require that calibration processes are based on validated methods. International standard are a means of documenting best practices and subjecting innovative measurement techniques to global peer review and adoption by consensus.

Correct implementation of standardized methods and adherence to specifications demonstrates proficiency and instils confidence. Contributions to standardization adds value to EMPIR projects by effectively disseminating know-how.

Different aspects of underwater acoustics is covered by two technical committees; ISO/TC43/SC3 and IEC/TC87/WG15. In ISO/TC43/SC3, three new work items have begun on standards for measuring ship noise, ocean ambient sound and the effectiveness noise abatement for offshore windfarm construction – all of which will require traceable calibrations in the frequency range from a few hertz to 200 Hz where traceability and metrology is weakest. The project has also featured in a meeting of IEC/TC87/WG15 to raise awareness of potential future contributions on methods of hydrophone calibration, especially at low frequencies.

Finally, while the standardisation group on acceleration and vibration, ISO/TC108/WG34 has been dormant recently, the project developments are providing an incentive for a meeting to be organised.

CONFERENCE PARTICIPATION

There is an ongoing drive in the project team to present research results at prominent conferences. Presentations have been made to the German Acoustical Society conferences (DAGA), on secondary microphone calibration in 2021 and on primary calibration, and specifications of infrasound measurement equipment in 2022. Two presentations have also featured in the XXIII IMEKO World Congress, on developments in low-frequency seismic calibrations.

Further contributions to IMEKO are planned with a paper on acoustic pressure measurements based on Fabry Perot interferometry, and another on low frequency primary vibration calibration using a multi-component shaker. The conference takes place in Croatia in October 2022.

We are also excited to report about a further collaboration within IMEKO. The project team are developing plans for a Workshop in conjunction with

IMEKO TC 22, on **traceable laboratory calibration of seismometers at very low frequencies.** The workshop is scheduled for Q1 2023, Full details will appear on our project website in due course.

Conference submissions have also been made to the 24th Int. Congress on Acoustics (ICA2022) on the influence of common microphone defects on low frequency measurements, and to the European Geophysical Union (EGU22) on uncertainty propagation in on-site calibration.

The following paper has also been published: Samuel K. Kristoffersen. Updated global reference models of broadband coherent infrasound signals for atmospheric studies and civilian applications. Earth and Space Science. DOI

Details of completed presentations and publications, including links to download the articles can be found at the project website.

TEAM MEMBER 'BUSINESS CARD'

In each issue of the Newsletter we will introduce a selection of the participating institutes to highlight their contributions to the project and their wider activities. This time we introduce the partners BGR, NPL & ASN.

Die Bundesanstalt für Geowissenschaften und Rohstoffe

The Federal Institute for Geosciences and Natural Resources (BGR) is subordinate to the Federal Ministry for Economic Affairs and Climate Action (BMWK) of Germany. BGR is the central geoscientific authority advising the German Federal Government in all geo-relevant questions and its responsibilities include the promotion of science and industry through geoscientific research and development, as well as consulting, knowledge and technology transfer. The BGR participates in both national and international research projects, thereby conducting the research and development necessary for consulting, which forms the basis for the professional fulfillment of BGR's tasks and comprise methodological and instrumental geoscientific development work and its implementation in practice.

One main task of the BGR is the monitoring of compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which is assigned to BGR's Sub-Department B4.3 (Federal Seismological Survey, Nuclear-Test Ban). BGR has a large experience in the field of geophysical data management, data processing and event detection as a National Data Centre (NDC) of the CTBTO and beyond. The institute contributed to the technical planning for the International Monitoring System (IMS) and BGR operates a total of four of the 321 IMS stations, each one seismological and infrasound stations located in the Bavarian Forest and Antarctica, among several regional arrays, to detect explosive events and natural sources underground and in the atmosphere. As an NDC, BGR thus acts as the technical contact for the Federal Government and the CTBTO, providing expertise on all issues pertaining to CTBT verification. Further, the BGR has the responsibility for maintenance and operation of German measuring stations involved in the IMS.

As part of the Infra-AUV project, BGR will provide access to its remote seismological and infrasound stations in the Bavarian Forest for on-site calibration tests for vibration and sound in air.

www.bgr.bund.de

National Physical Laboratory

NPL is the UK's National Metrology Institute, providing the measurement infrastructure and delivering the UK Measurement Strategy on behalf of the UK government's Department for Business, Energy and Industrial Strategy. NPL undertakes excellent science and engineering to deliver impact for the UK and provide the measurement capability that underpins the UK's prosperity and quality of life, undertaking work to address metrology requirements within the national challenges for several identified strategic areas: energy and environment, advanced manufacturing, life sciences and health, digital transformation, and security and resilience. NPL collaborates widely with other NMIs, academia, and with the smallest and the largest commercial and industrial organisations.

Underwater Acoustics is one of over twenty scientific areas covered by NPL's research programmes and is a key underpinning technology in marine science for: offshore energy exploitation (including oil and gas and renewable energy); oceanographic and environmental studies; and defence and security. NPL's capability enables the protection and sustainable exploitation of marine resources through provision and dissemination of traceable acoustic standards, enhancing the competitiveness of the marine technology industry, underpinning strategic offshore applications for energy and defence, and protecting the marine environment from pollution. The metrology infrastructure ensures a robust legislative framework to protect the ocean environment without introducing unnecessary barriers to exploitation of the seas.

NPL is an internationally leading metrology laboratory for underwater acoustics, and some of our facilities for underwater acoustics are unique within Europe. These include state-of-the-art laboratory tanks with precision positioning systems, an acoustic pressure vessel which can simulate ocean conditions in the laboratory, a large open-water facility located on a and low frequency pressure calibrations facilities (the improvement of which are the subject of the Infra-AUV project).

NPL has an active research programme in many aspects of underwater acoustics in addition to low frequency calibration, near-field techniques, optical methods for acoustic measurement, and the measurement and analysis of ocean noise.

Of course, scientific excellence itself does not guarantee that research discoveries create their desired impact or benefits in society. Consequently, NPL invests heavily in the dissemination of technology and knowledge, working closely with stakeholders and stakeholder networks, using a variety of knowledge transfer mechanism, activities and media. NPL is therefore well-placed to make a strong contribution to the Infra-AUV project, and realise its wider impact.

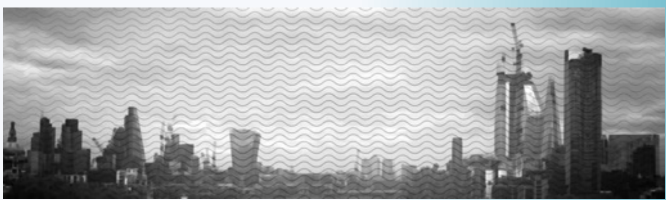
npl.co.uk

acoustic sensor networks

Acoustic Sensor Networks Limited

Acoustic Sensor Networks (ASN) is a micro-SME pioneering distributed monitoring of environmental noise, and specialising in innovative and unusual acoustical measurement and metrology applications.

ASN develops distributed noise monitoring solutions based on the latest generation of low-cost MEMS microphones and IoT hardware. The rich data sets generated by these solutions allow the application of advanced analytics to provide new insights in environmental noise, ultimately leading to a better understanding of how noise impacts the health and experience of citizens. Through innovation in noise measurement we believe our cities can sound better.



ASN offers specialist knowledge of acoustical metrology combined with practical experience in working closely with the stakeholder communities. ASN also chairs IEC/TC29 on Electroacoustics where the developments in acoustical technology can be adopted into new standardisation projects.

AcousticSensorNetworks.co.uk

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EMPIR EURAMET
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States