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Dear members,

With the winter solstice behind us, we are now steadily moving towards the warmer months, with less cold rain, less cold wind, and less cold generally. Some people like winter, but I don't care for it. Although we have been somewhat blessed recently, with no crickets or cicadas invading our noise measurement results, and some long stretches of calm clear days and nights to get monitoring jobs out of the way. I guess there is one upside to winter.

There's been plenty going on in the ASNZ over the last few months, with the organisation of the 2020 joint ASNZ / AAS conference in Wellington gaining significant momentum, as well as the planning of several branch meetings and the sharing of much knowledge at the Auckland Lunch Bunch events.

Although purely by coincidence, this winter has also provided me with some motivation to strengthen our ties and knowledge sharing with the New Zealand Planning Institute (NZPI) and the Resource Management Law Association (RMLA). Our membership can help the planning profession a great deal by providing a good understanding of the challenges the acoustics profession faces, demystifying some of the more complex but frequently used acoustical terminology and assessment concepts, and letting planners know how they can write the best briefs and understand our reports.

Our profession can also benefit from a greater understanding of the planning framework and the matters our advice needs to consider. For example, a District Plan is more than a set of rules – it is a document that is unique to each District within New Zealand, and identifies a set of objectives, policies and rules which in unison, seek to give effect to the strategic resource management objectives for that district and for each zone within it. Although detailed knowledge of such matters is not a core component of our acoustics work, if we are involved in resource management work, it is important that we hold a basic understanding of the process and framework. Understanding what the objectives and policies of a District Plan are trying to achieve is often a critical consideration for determining what a reasonable level of noise might be. They differentiate one zone from another, and this means that no two rural, residential or business zones between Districts or within a District are going to be same. Understanding this is often critical to a good outcome.

We have already held a few joint events with the NZPI and we have more coming up, including a few possible ASNZ branch events around New Zealand involving the NZPI where we can hear from the planning industry on how acoustics experts can help to achieve good quality environmental outcomes.

Submission of CPD records is going to be due for a portion of the membership soon, so make sure you are making a note of every paper published, conference attended, society event organised or paper read to ensure it's nice and easy when the time comes. Don't forget that you can download the form from the ASNZ website – it will tell you what you can claim CPD points for and how to file.

Cheers,

Jon Styles

President of Acoustical Society of New Zealand

(From left) Wyatt Page, Noor El-Matary, Lindsay Hannah

Nau mai to the second New Zealand Acoustics (vol 32, 2019, No 2). Those of you who read the Editor's write up will know from the previous issue that we are in the middle of transferring the physical production of the journal, which has allowed Wyatt and I to concentrate on co-ordinating, sourcing and reviewing content.

This is the first edition under the new transfer with Noor El-Matary taking on the new role as Creative Content and Production Manager. Welcome aboard Noor! Wyatt and I would also like to specifically mention the ASNZ Board for their on-going support including Jon Styles, President, for making the changeover as smooth as possible. If any of our members have any comments or feedback on the new journal please contact us as we always want to hear any feedback and comments. In this edition we have our usual mix of technical papers as well as RMANet, news, quiz, and calendar. Thanks to all our members for your on-going support.

Lindsay Hannah & Wyatt Page

Principal Editors

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NEWS

RESEARCHERS ARE GATHERING FISH SOUNDS TO MONITOR WATERWAYS

Fish create a rich orchestra of underwater sounds as they hunt, spawn and defend their nests and these sounds are now forming the basis of new methods to monitor the health of waterways.

Dr Simon Linke, an ecologist and sound engineer with Griffith University's Australian Rivers Institute, said studying the sounds made in nature could provide valuable information about the environment. An underwater microphone, or hydrophone, is cast into the water, which records audio and can transmit the sound and data back to an office. Particular sounds like fish calls have been catalogued and can be identified by computer systems, meaning data can be automatically processed from the passive audio recordings and used to construct findings on the health of the river system. The scientists also hope the system could be used as an early detection system for invasive pest species like Tilapia.

Tim Swanston, ABC News

More information – https://www.abc.net.au/news/2018-12-30/fishsongs- harbour-secrets-on-waterway-health/10669816

PLANTS ATTUNED TO THE SOUND OF WATER

A researcher has been breeding dissent from the science community with a series of experiments she believes proves that plants are making intelligent choices and listening to sounds. Biological intelligence expert Monica Gagliano from the University of Sydney said it was possible to train plants in the same way as a dog. Plants are known to be able to find nearby water by sensing its humidity gradient. "But then I recorded the sound of water and substituted the real presence of water inside a pipe with just the sound," Dr Gagliano said. "Even if the actual water isn't there and it's just the mere sound of it, they will grow towards it."

> "Even if the actual water isn't there and it's just the mere sound of it, they will grow towards it."

Malcolm Sutton, ABC News

More information – https://www.abc.net.au/news/2019-01-15/ researcher-teaching-plants-dog-tricks/10709530

FAKE NOISES TO BE ADDED TO EV'S IN THE EU

All new models of electric cars sold in the European Union must now make artificial noise under certain conditions, reports BBC News. Acoustic Vehicle Alert Systems (aka, AVAS) will need to be installed in new models of hybrid and electric cars introduced from today onward, and all existing models by July 2021. With an AVAS installed, vehicles will need to make a sound while traveling under 12 mph, or while reversing. Due to the absence of an internal combustion engine, electric vehicles can be a lot quieter than their gas-powered counterparts. However, this lack of noise can mean that they pose a danger to other road users, especially people who are blind or partially sighted.

In a written submission to the British Parliament from November 2017, the charity Guide Dogs pointed to research that says electric and hybrid vehicles are 40 percent more likely to be involved in an accident which causes injury to a pedestrian.

Different manufacturers will be able to decide exactly what their AVAS will sound like, but the EU's legislation says that the sound should be similar to (and not louder than) a traditional combustion engine. It should also give pedestrians an idea of what the vehicle is doing by, for example, synchronizing with a vehicle's speed. Jaguar has already revealed what its I-Pace will sound like, and Nissan announced a concept vehicle back in 2017 that "sings" as it drives.

The EU isn't the only regulator that's introducing fake noise rules around electric vehicles. In the US, the National Highway Traffic Safety Administration will require that all hybrid and electric vehicles emit artificial noise by September 2020, although they'll have to emit the sounds up to the slightly faster speed of 18.6 mph.

DEMENTIA SYMPTOMS REVERSED IN MICE – USING ULTRASOUND

A promising study that reversed dementia symptoms in mice is to begin human trials in Queensland, thanks to $10 million in federal funding. Researchers have found they can blast away the "toxic plaque" from the brain using non-invasive, non-toxic treatments and an ultrasound. So far, scientists at the Queensland Brain Institute have been able to inject "micro bubbles" in the brains of mice which, when used with an ultrasound, fully restored their brain function. Professor Peter Hoj from the University of Queensland said urgent action, like the clinical trial, was critical. Professor Gotz said researchers had shown the approach worked in sheep and mice, and the next step was to go into human participants and start with the "safety trial".

Brittney Kleyn, ABC News

More information – https://www.abc.net.au/news/2018-12-18/dementia-cure-possibleafter- breakthrough-qld-study/10629688

FRENCH COURT HEARS CASE OF MAURICE, THE FAMOUS 'NOISY' COCKEREL

Retired couple say rooster's 'abnormal noise' disturbs them at holiday home. Maurice the cockerel, France's most famous bird, whose piercing dawn call sparked neighbours to take legal action over noise pollution, has finally had his case heard in court. A local court in Rochefort has begun examining the case of a dispute over the bird between neighbours on the Île d'Oléron. Two pensioners complained that Maurice was making abnormally high levels of noise that disturbed the peace at their second home on the island when he crowed every morning at 6.30am.

The dispute, which has run for more than two years, has been billed as a symbolic standoff between two ways of life: on one side are the islanders on the picturesque Île d'Oléron off the Atlantic coast, who say they have always kept chickens; on the other are people arriving from other areas of France to invest in second homes on the island.

Maurice has received support from all over France through a petition defending his crowing; in recent months his fame has been used to draw attention to key causes, such as posing this winter wearing a yellow hi-vis vest in favour of the gilets jaunes protesters. Supporters have created an "I am Maurice" banner on social media and and even the head of one local authority, Dominique Bussereau, tweeted his solidarity. Although Maurice was not in court, some supporters stood outside with cockerels in their arms. The couple who filed the legal case for "abnormal noise disturbance" were described in court as quiet pensioners aged 65 and 70, of modest income. They had bought a second home on the Île d'Oléron and complained of the noise every morning at 6.30am. Their lawyer said they had bought their house in 2004, long before Maurice was born in 2017. They were not in court because of the intense media interest in the case. They wanted the court to rule that the noise must stop, the lawyer said. Lawyers for Maurice's owner, Corinne Fesseau, argued that his crowing did not constitute "abnormal noise" on the island.

The arguments in court focused on whether or not Saint-Pierre d'Oléron, Maurice's home town on the island, which has 7,000 residents in winter and 35,000 in summer, could be described as a rural area or not. Lawyers for the retired couple said it was considered a built-up urban area. A verdict is due on 5 September.

In 1995, faced with a similar case that led to a death notice being served on a cockerel, a French appeal court declared it was impossible to stop a rooster crowing. "The chicken is a harmless animal so stupid that nobody has succeeded in training it, not even the Chinese circus," that judgment said.

More information – https://www.theguardian.com/world/2019/jul/04/maurice-the-cockerel-noise-polluter-case-heard-in-court

Photo: Xavier Leoty/AFP/Getty Images

VIRTUAL REALITY EXPERIENCE REPLICATES LIFE AS A CHILD WITH HEARING LOSS

Leading children's charity, The Shepherd Centre, is launching a ground-breaking virtual reality (VR) experience that immerses the user in to a world of silence enabling them to feel first-hand what life is like for a child with hearing loss. The Shepherd Centre supports children with hearing loss of all levels to learn to listen and speak but the clinical staff that work there have often struggled to articulate just how isolating life with even just moderate hearing loss can be. For over a year and a half, the innovative organisation worked with Surry Hills based agency Paper Moose to develop a confronting user experience that allows the user to understand how isolating hearing loss can be.

Senior Communications Manager at The Shepherd Centre, Jo Wallace worked with one of The Shepherd Centre's graduates Tyler Potaka, his teacher and their class to recreate a primary school setting where a child with hearing loss experiences social isolation and misunderstanding with just a moderate level of hearing loss. The development of the clip became an educational experience in itself for Tyler's class as they learnt some of the challenges that their classmate experienced on a daily basis.

A behind the scenes clip was made to support the VR technology and can be viewed by scanning the QR code below.

More information – www.shepherdcentre.org.au

WATCH VIDEO

YouTube video – 'Step in the shoes of a child with hearing loss'

Photo screenshot taken at 1:24

UK AUTHORITIES WILL TEST 'NOISE CAMERAS' TO CLAMP DOWN ON LOUD VEHICLES

Authorities in the UK are about to test advanced noise detection systems in an effort to crack down on louder than allowed vehicles across the country.

The devices commissioned by the government will be able to detect motorists and bikers with vehicles exceeding legal noise limits and automated number plate recognition will identify the offenders.

All vehicles made since 2016 and sold in Europe are limited to 74 decibels, but aftermarket exhausts systems that are available for cars and motorcycles can be significantly louder than this.

Sky News reports that a prototype noise detection device will be tested at several locations over the next seven months in the UK.

Transport Secretary Chris Grayling says he is determined to make loud exhausts a thing of the past.

"Noise pollution makes the lives of people in communities across Britain an absolute misery and has very serious health impacts. This is why I am determined to crack down on the nuisance drivers who blight our streets."

Motorcycle Industry Association chief executive Tony Campbell said noise detection devices are needed to stamp out illegal exhausts fitted by some bikers.

"With growing pressure on the environment, including noise pollution, illegal exhausts fitted by some riders attract unwanted attention to the motorcycle community and do nothing to promote the many benefits motorcycles can offer."

Trials will determine if a vehicle has breached the legal noise limit by taking into account the class and speed of the vehicle relative to the location of the noise detection device. If the trial is successful, the technology could (or should we say will?) be introduced across the UK.

https://www.carscoops.com/2019/06/uk-authorities-will-test-noise-cameras-to-clamp-down-on-loud-vehicles/

Fake exhaust on a BMW X5

Photo: Stefan Baldauf / Guido ten Brink for CarScoops

A Lamborghini Aventador scores 71.2dB

2020 INTERNATIONAL YEAR OF SOUND

2020 will be the International Year of Sound. The International Year of Sound is a global initiative to highlight the importance of sound and related sciences and technologies for all in society. The International Year of Sound will consist of coordinated activities on regional, national and international levels. These activities will aim to stimulate the understanding throughout the world of the important role that sound plays in all aspects of our society. As well, these activities will also encourage an understanding of the need for the control of noise in nature, in the built environment, and in the workplace.

Sound plays an important role in all human activities and applications of acoustics are found in almost all aspects of modern society. Sub-disciplines include aeroacoustics, audio, signal processing, architectural acoustics, bioacoustics, electro-acoustics, environmental noise, musical acoustics, noise control, hearing and psychoacoustics, physical acoustics, speech, ultrasound, underwater sound and vibration. Sound is an essential part of communication between humans - in the form of speech, as a sound of warning, and also in music and creative sounds. However there is a concern about too much sound, which then becomes noise and needs to be controlled to ensure acceptable and safe living and working environments.

International Year of Sound 2020

"...a global initiative to highlight the importance of sound and related sciences and technologies..."

'ALIEN-LIKE' NOISES IN BACKYARD

An Auckland resident was left puzzled when she heard a "mythical" creature making 'alien-like' noises outside her Mt Albert property on Monday evening. The resident, who wished not to be named, posted the mysterious video to a local Facebook page asking: "Does anyone know what kind of animal/mythical monster is making this sound?" The video shows the resident shining a torch into the darkness of their backyard while a spine-chilling noise can be heard ringing out of the bush. Some commenters responded in horror, while others identified the "monster" as a possum.

A spokesperson from the Department of Conservation confirmed the alien-like noise as a possum. "Definitely a possum, they normally make this sound when they've met another one," they told Newshub.Researchers have documented possums making 18 different sounds, according to Australian Geographic.The sounds include "grunting, growling, hissing, screeching, clicking and teeth-chattering calls, many of which would not be out of place on a horror movie soundtrack".

Newshub

SOUND LEVEL METER B&K 2245 IS RELEASED

Designed to simplify noise measurement and analysis, B&K 2245 is a complete, easy-to-use package that can be used as a stand-alone noise measurement device, or with a range of user-friendly mobile and PC apps, each tailored for specific applications including environmental noise, and occupational noise, and stationary exhaust noise testing.

The apps provide features specific to their application, as well as enabling a comprehensive range of measurement capabilities on the sound level meter in both standalone and app-controlled modes. For example, the environmental noise app includes intuitive marker creation and editing tools for isolating sounds in the field and office. It also unlocks a wide range of parameters on B&K 2245 including statistics, frequency analysis, logging and audio recording. Each device can be licensed for more than one app, so switching tasks is as easy as switching apps.

The sound level meter's robust rubberized body provides a safe and secure grip, and is dust and water resistant to IP55, making B&K 2245 suitable for use in a wide range of environments. In addition, the clean and simple user interface makes it easy and comfortable to use. In handheld measurement situations, all buttons can be easily reached with your thumb while maintaining a safe grip. When measuring on a tripod, the mobile apps enable full control without disturbing the measurement.

To keep the sound level meter ready for use and protect measurement data, there is an optional smart docking station. The docking station is a high-speed charger that can also automatically transfer data stored on the sound level meter to a network drive, leaving B&K 2245 ready for the next survey.

Do you have a new product?

Let the editors know and we can include it in the next issue.

STUDENT PRIZE

At the 2018 Annual General Meeting of the Acoustical Society of New Zealand, it was decided that the Society would commit $2500 annually for the awarding of student prizes. This amount will be distributed to deserving students who have undertaken a project related to acoustics as part of the studies at a New Zealand University. A staff member can bid for money from this pot by emailing: ***Mike Kingan (m.kingan@auckland.ac.nz) by the 30th of September.***

Email invitations to bid for money will also be sent directly to staff who are known to be research active in acoustics. The bid should describe what the prize will be awarded for and how many students are under consideration for it. The awards can be for undergraduate or postgraduate students, but should pertain to work either wholly or partially undertaken in the 12 months prior to the award being made.

A committee from the Society will then determine the distribution of money amongst the various institutions by the 14th of October who will inform staff of the success, or otherwise, of their bid shortly thereafter. The staff member should then coordinate the award of a prize or prizes to a student or students based on the merit of their work and in consultation with a local representative from the Society. The Society will provide certificate/s and money for the prize/s. If no student paper or project is deemed worthy of an award then no award need be made.

Examples of Prizes might include

Outstanding performance in an undergraduate student project related to acoustics,

OR

completion of an outstanding thesis or conference/journal paper on a subject related to acoustics.

FEATURES

PERFORMANCE OF SOUND SOURCE LOCALISATION FOR BIRD CALLS IN NATIVE NEW ZEALAND BUSH

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Original peer-reviewed paper

ABSTRACT

This study directly compares the performance of existing source localisation algorithms using microphone arrays for bird call localisation in native New Zealand bush. Experiments were carried out to investigate the performance of generalised cross correlation with phase transform (GCC-PHAT) and multiple signal classification (MUSIC), and their variants using recordings of North Island brown kiwi calls played from a loudspeaker acquired in a native New Zealand bush environment. Four different microphone array configurations were tested at two locations in the bush.

Experimental results showed that GCC-PHAT had the best accuracy for most array configurations. Conventional narrowband MUSIC consistently performed the worst, whereas the wideband MUSIC was comparable to GCC- PHAT in some tests however the offset in the estimated angle was much higher. A variant of wideband MUSIC performed similarly to conventional wideband MUSIC, but it did not outperform GCC-PHAT. The small triangle array achieved the best performance by a large margin. The results also imply that the square array shape may perform better than a triangular array when their sizes are similar.

INTRODUCTION

New Zealand has a very short history of human habitation compared to many other continents and islands on earth. It has been less than 1000 years since the first human arrived in New Zealand [1]. Before the arrival of human beings, the animal inhabitants on the islands of the country had mainly been birds and insects. Since the introduction of predatory mammals, many of the native bird species have become extinct or are in extreme danger of extinction. The latter includes the iconic kiwis that represent the country. In order to save these bird species from further extinction and regenerate their population, various conservation efforts exist across the country [2].

Bird conservation requires monitoring their ecology; a process which often relies on acoustic information to determine the presence and abundance of bird species using their calls [3, 4]. In dense forest or mountainous terrain, it is often difficult to visually identify birds but many have easily identifiable calls. One of the commonly used techniques currently used in bird ecology monitoring is the primitive "call count" [5], which requires human observers to manually count the number of calls heard [6]. This approach tends to be extremely time consuming and can only cover small areas. Due to the short periods of survey, it does not tend to be very useful for observing patterns that occur at specific times [7]. It also relies heavily on each observer's expertise and hearing capability [8].

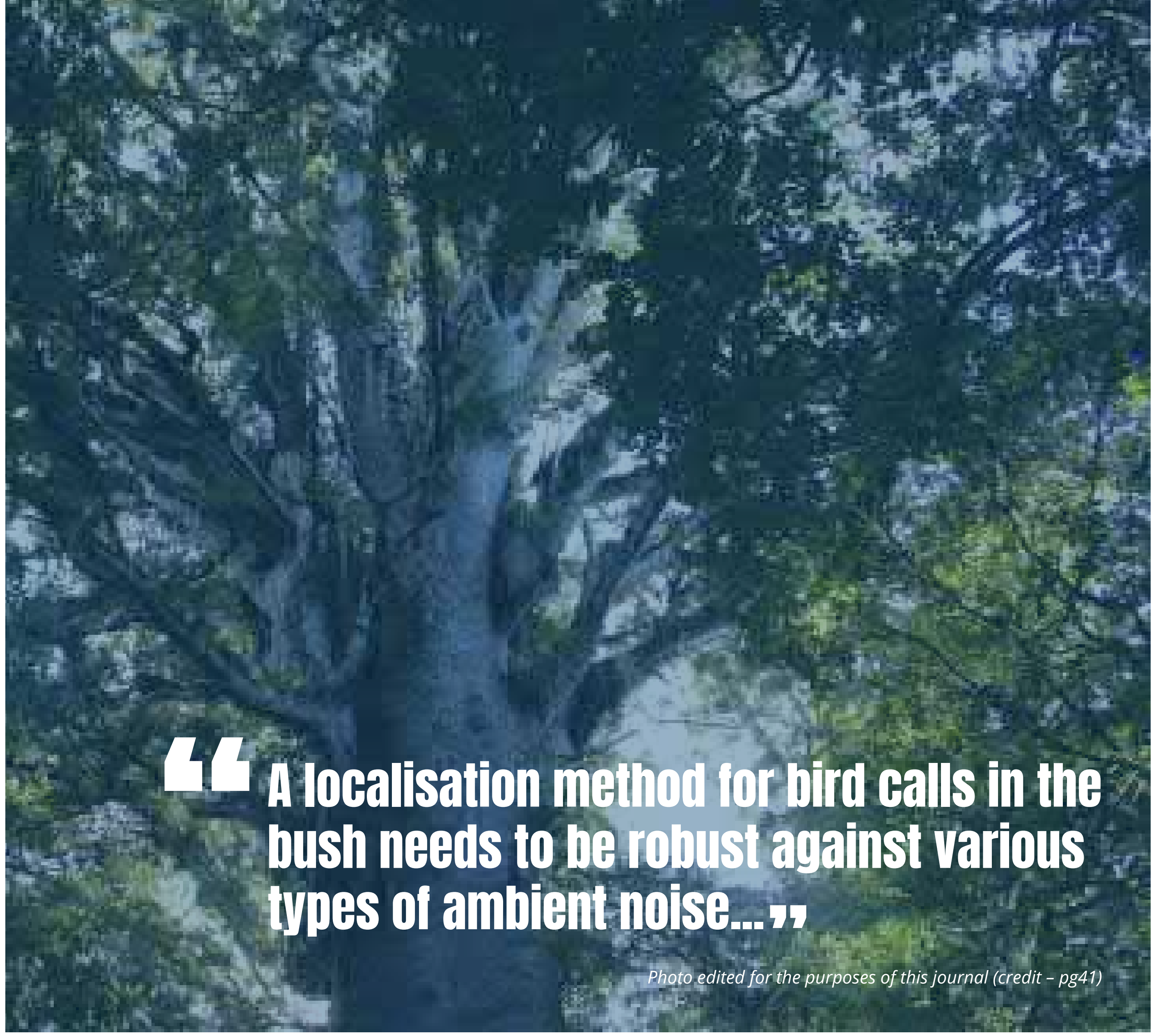


Photo edited for the purposes of this journal (credit – pg41)

Automating this process would save many hours of time and has the potential to be much more comprehensive and accurate. Currently many acoustic recording units are available that fit the requirements for this task. They are weatherproof, have high battery and memory capacities and can be run for long periods of time [9]. Increasingly these devices are being used by conservationists instead of traditional call counts. Various attempts have been made to identify bird species from their calls [10, 8, 11, 12, 13]. Similarly some previous studies suggest using microphone arrays for localising birds because bird population could be inferred from their location distribution [14, 15, 3, 16, 17].

In New Zealand the term *bush* refers to the native forests which are normally very dense. In the bush, "Tall trees tower above shrubs and younger trees. Beneath these grow ferns and mosses. Sunlight filters through the lush foliage, and birds and insects thrive." [18] Thus, a localisation method for bird calls in the bush needs to be robust against various types of ambient noise, both natural and anthropogenic, and sound reflections and diffractions caused by the terrain and foliage. Various source localisation algorithms using microphone arrays currently exist in the field of acoustic signal processing; however, the majority of existing source localisation techniques are designed for localising human speakers in indoor environments where the acoustic properties such as reverberation and background noise are very different from a native forest. Modelling acoustic properties in outdoor environments is much more difficult compared to indoor rooms and buildings because of the complexity of the problem [19]. A few studies investigated localisation performance in a forest setting using microphone arrays [14, 15, 16, 17, 20, 21, 22]; however, no direct comparisons between existing localisation algorithms or microphone array configurations have been reported.

This study will focus on directly comparing the localisation performance of various existing source localisation algorithms using different microphone array configurations in native New Zealand bush using the call of a North Island brown kiwi (Apteryx mantelli). The localisation techniques that will be investigated are generalised cross correlation (GCC) with phase transform (PHAT) [23], and multiple signal classification (MUSIC). Variations on MUSIC that aim to improve performance in the forest environment and with bird calls will also be compared. A part of the results included in this paper has been reported previously [24].

The rest of this paper is organised as follows. After a brief investigation of acoustics in a typical New Zealand bush environment in Section 2, Section 3 presents source localisation algorithms investigated in this study. Section 4 is devoted to the details of the experiments followed by results and discussion presented in Section 5. The paper is concluded with remarks in Section 6.

ACOUSTICS IN THE BUSH

To understand the acoustics in the bush environment, impulse responses were measured at three different locations in the Parry Kauri forest [1], atypical New Zealand bush. The impulse responses were measured by a microphone fixed in place and a loudspeaker placed on the ground at one of the locations from A to C. Distances from the locations A and B from the microphone were approximately 20 metres; however, the two locations were in different direction. The shrubs and undergrowth on the direct path between location B and the microphone were much denser than that between location A and the microphone, causing more reflections and diffractions. On the other hand, location C was closer to the microphone (approximately 10 meters) with no major obstructions on the direct path between the microphone and loudspeaker.

Figure 1* and *Table 1 respectively show the energy decay curves and reverberation time T_{60} calculated from the measured impulse responses using the early decay time (EDT) and T30 [25] at three octave bands where the majority of the energy of bird calls reside. As seen in ***Figure 1*** the energy decay curves for location A and C show significant "cliff-type" decay indicating the direct sound is very strong [26]. This is not the case for location B where the direct sound is heavily attenuated because of the obstructing shrubs and undergrowth causing low direct-to-reverberation ratio (DRR) [27] of the measurement. The smaller EDT at locations A and C compared to B for the 4 kHz octave band suggests this trend is more obvious for higher frequencies, which is natural as sound waves with shorter wavelengths (i.e. higher frequencies) are more susceptible to obstructions. After the sharp energy drop caused by the direct sound, the energy decay curves for all three locations show a "sagging" pattern, which usually occurs when reverberation is two dimensional, i.e. reverberation is mainly caused by sound reflection on the surfaces vertical to the ground [26]. This should be the case for all locations because there is no major reflective material above the bush. In addition, the sound absorption by the dense undergrowth (seen in location B in particular) would also contribute to making the reverberation two dimensional. In terms of late reverberation, the results indicate a bush can be fairly reverberant given that the measured reverberation time using T3 is around 1 second.

Overall these measurements suggest the technique suitable for bird call localisation the New Zealand bush has to be robust to reverberation and be able to cope with measurements with low DRR. The scope of this study is to answer the question: "Which of the conventional source localisation method would achieve the most accurate performance in typical New Zealand bush environment?"

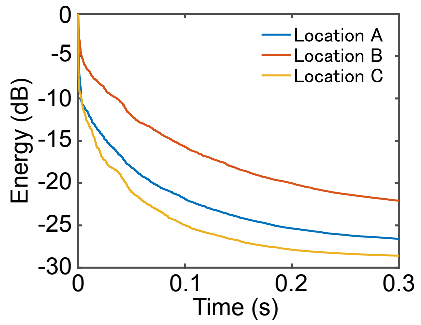


Figure 1 *– Energy decay curves of the impulse responses measured at different locations in a typical New Zealand bush.*

LOCALISATION ALGORITHMS

In this section, the sound source localisation algorithms investigated in this study are summarised.

Problem Setup

Assume a sound wave propagated from a sound source and is recorded by an *M*-channel microphone array. When the distance between the source and two microphones is assumed to be much larger than the aperture size of the microphone array, the sound wave can be treated as a plane wave [28]. The sound wave will reach the closest microphone before the other, creating a time lag between the signals appearing on the recordings from the microphones. The sound source is localised using this time lag, also known as time difference of arrival (TDOA).

Let the signal recorded by the microphone *m* ($m = 1, 2, \cdots, M$) be defined in the frequency domain as

$$X_m(\omega) = A_m(\omega)S(\omega) + N_m(\omega)$$

where ω denotes the angular frequency, $A_m(\omega)$ is the transfer function between the sound source and the microphone *m*, $S(\omega)$ is the signal emitted by the source, and $N_m(\omega)$ is the ambient noise combined with the internal noise of the microphone *m*.

Location	Early Decay Time (s)			*T* 30 (s)		
Frequency (Hz)	1000	2000	4000	1000	2000	4000
A	0.08	0.02	0.06	1.23	0.90	1.51
B	0.04	0.10	0.41	1.17	0.96	2.07
C	0.08	0.08	0.06	1.08	0.94	0.77

Table 1 *– Reverberation times measured at different locations in a typical New Zealand bush. Frequencies denote the centre frequency of each octave band.*

[1] *Details of the forest are summarised in Section 4.3*

Generalised cross correlation

The GCC has been one of the most commonly used techniques used for sound source localisation for the last few decades. While it has been widely used for speaker localisation, a few recent studies also applied the technique to bird call localisation [4, 29]. Its popularity comes from its robustness in practical environments, being easy to implement and working well in real time applications. Due to its sensitivity to noise and reverberation, it is most often seen in use with various types of weighting function [30].

The GCC is calculated from the signals of a pair of microphones, microphone p and q shown in ***Figure 2***, given by

$$r_{pq}(\tau) = \int_{-\infty}^{\infty} W(\omega) X_p(\omega) X_q^*(\omega) e^{j\omega\tau} d\omega$$

where $W(\omega)$, j and * represent the weighting function, the imaginary unit, and complex conjugate, respectively. The TDOA is estimated by searching for the maximum peak of $r_{pq}(\tau)$ in (3), which is then converted to the source angle by (4).

$$\hat{\tau}_{pq} = \arg\max_{\tau} r_{pq}(\tau)$$
$$\hat{\theta}_{pq} = \sin^{-1}\frac{c\hat{\tau}_{pq}}{d_{pq}}$$

Here d_{pq} and c are the distance between the microphones p and q, and the speed of sound, respectively, and $\hat{}$ denotes an estimated value. Since the spatial resolution of localisation using GCC is determined by the sampling rate of the recording, interpolation is often applied to $r_{pq}(\tau)$ before searching the peak. In this study, smoothing spline was utilised for the interpolation.

For the weighting function, phase transform (PHAT) and maximum likelihood (ML) are well-known and many variants of them have been proposed. PHAT is known to offer high robustness to reverberation, whilst ML performs better at dealing with low signal to noise ratios (SNR). In this study, PHAT was chosen for the weighting function given by

$$W_{PHAT}(\omega) = \frac{1}{|X_p(\omega) X_q^*(\omega)|}$$

GCC-PHAT with multiple microphone pairs

Because GCC can be applied only to a pair of microphones, an algorithm to incorporate the output of GCC from more than one pair of microphones needs to be introduced. The algorithm works using the distance and angle offset between microphones, and makes sure all the pairs are localising relative to the same direction. These angle offsets are calculated by

$$\delta_{pq} = \mathrm{atan2}(\Delta y_{pq}, \Delta x_{pq})$$

where δ_{pq} is the angle offset for the microphone pair pq, atan2() is the arctangent with two arguments (four-quadrant arctangent) [31], and Δx_{pq} and Δy_{pq} are the distance between the microphones with respect to the x and y axes, respectively.

When any GCC localisation is carried out with a pair of microphones, it is impossible to determine whether the source is located in front, or behind the array, resulting in two possible results. This ambiguity is resolved by using angle estimates acquired from other microphone pairs with a different orientation. Because the false results all point in different directions, while the true results all point in the same direction, the offset spectra can be combined using a product as in

$$\bar{r}(\theta) = \prod_{p=1}^{M-1} \prod_{q=p+1}^{M} \bar{r}_{pq}\left(\frac{d_{pq}\sin(\theta - \delta_{pq})}{c}\right)$$

where $\bar{r}_{pq}(\theta)$ is the interpolated GCC of the microphone pair pq.

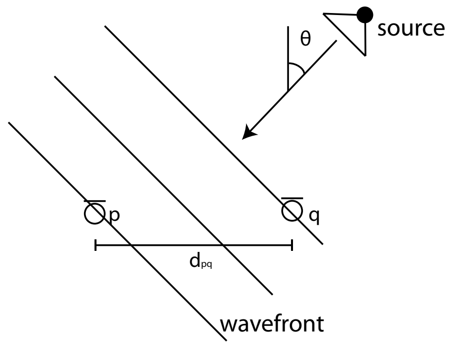


***Figure 2** – Time difference of arrival between two microphones.*

MUSIC

MUSIC is another commonly used technique for sound source localisation.

It can achieve a high spatial resolution [32], however it is computationally more expensive than the GCC. It also requires some preliminary information about the sound frequency of interest as the conventional MUSIC was designed for localising a single frequency sources. In this study, the conventional MUSIC and its two variants tailored to broadband sources are tested.

Narrowband MUSIC

The conventional MUSIC, called Narrowband MUSIC in this study, focuses on a particular frequency of incoming signals. A MUSIC spectrum is calculated from the microphone observation as shown in (8), then the angle of arrival is estimated by searching the peak of the MUSIC spectrum by

$$P(\theta, \omega) = \frac{1}{\sum_{n=L+1}^{M} |\boldsymbol{a}^H(\theta, \omega)\boldsymbol{v}_n(\omega)|^2}$$
$$\hat{\theta}(\omega) = \arg\max_{\theta} P(\theta, \omega)$$

where $\boldsymbol{a}(\theta)$ represents the steering vector [28] with respect to angle θ, ^{H} is the Hermitian transpose, and L (< M) is the number of sources, which is known *a priori* as $L = 1$. $\boldsymbol{v}_n(\omega)$ is the eigenvector corresponding to the n-th largest eigenvalue $\Lambda_n(\omega)$ of the spatial correlation matrix

$$\boldsymbol{R}(\omega) = E[\boldsymbol{x}(\omega)\boldsymbol{x}^H(\omega)] = \sum_{n=1}^{M} \Lambda_n(\omega)\boldsymbol{v}_n(\omega)\boldsymbol{v}_n^H(\omega),$$

where $\boldsymbol{x}(\omega) := [X_1(\omega), X_2(\omega), \cdots, X_M(\omega)]^T$ and $E[\cdot]$ denotes the expectation.

Wideband MUSIC

The narrowband MUSIC calculates the MUSIC spectrum from the signal of a single frequency; therefore it is only useful for the localisation of narrow- band signals. However, most bird calls are wideband, as in the case of the female kiwi call, or include a number of narrow bands, as in the harmonics of a male kiwi call [33], and as such wideband implementations of MUSIC have been explored. A previous study [34] extended MUSIC by weighting the MUSIC spectrum of each narrow band by the square root of the largest eigenvalue, which is known to represent the amplitude of the source signal of that frequency. This is given by

$$\bar{P}(\theta) = \sum_{\omega=1}^{F} \sqrt{\Lambda_1(\omega)}\, P(\theta, \omega)$$

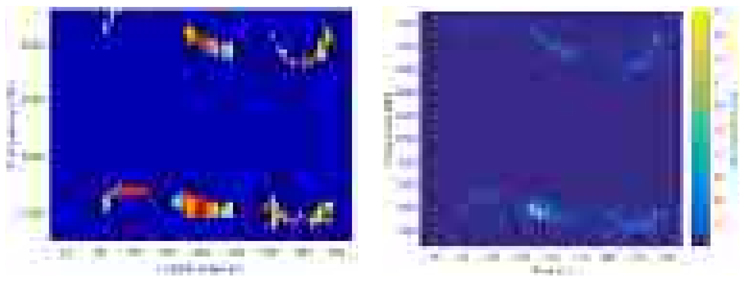
where $\bar{P}(\theta)$ is the weighted average MUSIC spectrum, $\Lambda_1(\omega)$ is the largest eigenvalue associated with the power of the source, F is the number of frequency bins to be averaged, and $P(\theta, \omega)$ is the narrowband MUSIC spectrum of frequency ω calculated by (8). The estimated direction is given by

$$\hat{\theta} = \arg\max_{\theta} \bar{P}(\theta)$$

In our implementation, the narrowband MUSIC spectra are first normalised before being weighted by the associated eigenvalue. This ensures that the algorithm will be resistant to spatial aliasing when used with microphone configurations which include microphone pairs that would cause spatial aliasing.

Dynamic MUSIC

Apart from the existing narrowband and wideband MUSIC, a modification of wideband MUSIC named "dynamic MUSIC" has been introduced. In addition to the algorithm found in wideband MUSIC, the algorithm determines which sections in time and frequency of the observed signal are important for localisation. The key difference between dynamic MUSIC and wideband MUSIC is that wideband MUSIC will be susceptible to interfering signals in the frequency range where dynamic MUSIC will remove sections with a power less than a threshold. Peaks in the wideband MUSIC spectra will relate to the correlation of different signals combined with the cumulative energy of the signal over the length of the recording. Thus, sounds that have a low energy that extend over a period of time as seen in typical New Zealand bush environments, such as the sound of rapidly flowing creek, will introduce an unwanted significant peak in the derived MUSIC spectrum. Dynamic MUSIC will only localise sources that have a power higher than a specified threshold, so these sources will not affect the result.



(a) *(b)*

***Figure 3** – An example of extracted time segments from a recording used in dynamic MUSIC, (a) Extracted segments; each colour shows time-frequency cells that belong to a segment, (b) Spectrogram of the recording used for extracting time segments.*

Let $X(\omega, l)$ be the short-time Fourier transform (STFT) of the input signal of an arbitrarily selected microphone of the microphone array, where l is the frame index. The frames where bird calls are likely to be active and those that predominantly include noise are respectively selected using a threshold as

$$I_s = \{l \mid |X(\omega, l)| > \Phi_s\}$$
$$I_n = \{l \mid |X(\omega, l)| < \Phi_n\}.$$

where $\varphi(l) = \omega\ |X(\omega, l)|$ is the L1-norm of the signal with respect to frequency at frame l, and Φl is the threshold determined empirically. In the rest of this paper, the input signals of the selected frames l_c and l_n are denoted as $X^c(\omega, l) := X(\omega, l)|_{l \blacksquare l_c}$ and $X^n(\omega, l) := X(\omega, l)|_{l \blacksquare l_n}$, respectively. Similar to the frame selection, the frequency bins of $X^c(\omega, l)$ that are likely to include the spectral components of bird calls are selected using another threshold as

$$\omega_c = \{\omega \mid \varphi(\omega) > \Phi_\omega\}$$

where $\varphi(\omega) = \sum_l |X(\omega, l)|$ is the L1-norm of the signal with respect to frame at frequency ω. Finally, the same procedure used in the wideband MUSIC is applied to the signal in the selected frame and frequency $X(\omega, l)|_{\omega \blacksquare \omega c, \blacksquare lc}$. An example of time segments extracted and the spectrogram of the recording used for the segment extraction are shown in ***Figure 3.***

EXPERIMENTS

The performance of the algorithms presented in Section 3 was investigated using sound recorded in an actual New Zealand bush.

Sound source

Among various native bird species, this study focused on the North Island brown kiwi as the sound source because priority has been given to the conservation of the species in New Zealand [35]. North Island brown kiwis show strong sexual dimorphism in their calls with significant differences being exhibited [33]. The female call is a wideband signal with moderate intensity across the frequency band from 1.5 kHz to 6 kHz. The male calls exhibit a harmonic structure in its spectrum where the pitch frequency is found around 1.5 kHz and the harmonics are seen up to 8 kHz. ***Figure 4*** shows the spectrogram of North Island brown kiwi calls used in the experiments. These signals were played by the loudspeaker set up in a forest as stated in Section 4.3.

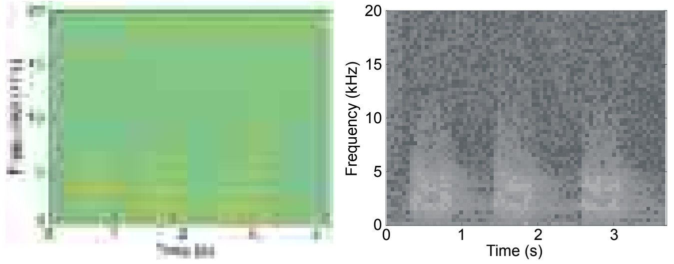
The kiwi has a large territory which it will defend actively. This territory will be as large as 50 ha, or 0.5 km^2[36]. The kiwi are nocturnal birds, so the most common time for them to call is at night, which means the kiwi calls are less to suffer from interference from other bird calls. An exception to this is with mating pairs of kiwi, where the female will often join the male in calling, resulting in a duet situation with multiple simultaneous calls.

Microphone array and recording system

A recording system with a microphone array that can realise different microphone configurations was developed for field recording. Two different configurations were adopted; a triangle with a central microphone and a square. Three different sets of microphone spacing were implemented to the triangular arrays. Within each array geometry, there were two different microphone pair sizes. Details of each array is summarised below.

- *Small triangle* has a radius of 29 mm, and the distance between smaller and larger pairs are 29 mm and 50 mm, respectively. It is expected that this configuration is able to avoid spatial aliasing up to higher frequencies but the spatial resolution would be lower compared to the following larger arrays.

- *Medium triangle* has the same microphone configuration as that of the small triangle, but double the spacing between microphones. It has a radius of 58 mm.



(a) male *(b) female*

Figure 4 – *Spectrogram of North Island brown kiwi calls used in the experiments, (a) Male call, (b) Female call.*

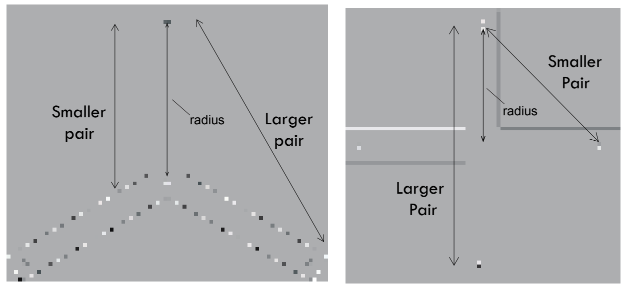


Figure 5 – *Microphone array configuration: triangle (left) and square (right).*

- *Large triangle* has an even larger spacing which is nearly double the size of the medium triangle; the radius is 100 mm. This configuration would result in an output with notable spatial aliasing due to the size of the larger pairs, but will have a higher spatial resolution than the smaller configurations.

- *Square* has only one size, with sides of 100 mm. This is the same length as the that of the shorter pairs in the large triangle. This will exhibit similar spatial resolution to the *large triangle.*

The recording system used a recorder (Zoom H6) with four omni-directional lapel microphones (RODE Lavallier). The recording was made at a 96 kHz sampling rate and saved with a lossless format (.wav). Ten recordings of the same call were made with each microphone configuration.

Recording environment

To make the experiment as realistic as possible, care was taken to choose a suitable recording environment. Different types of forest exhibit different acoustical characteristics and background noise so an environment was chosen that was similar to a kiwi habitat. The North Island brown kiwi is often found in Kauri forests around the North Island of New Zealand, so the Parry Kauri forest (36°25'00.4"S 174°40'12.7"E) in Warkworth, Auckland, New Zealand, was chosen as the field for recording ***(Figure 6).***

The forest is surrounded mainly by farmland and there are few local roads running close by. As kiwis are nocturnal the experiment took place after dusk between 7:00pm and 8:15pm on the 5th of September 2017 (NZST).

For this experiment, recordings were taken at two different locations within the forest which have been stated in Section 2. In the first location, location A, there was a small gully between the loudspeaker and the microphone array but the density of tree and undergrowth was relatively sparse so that the loudspeaker was in the direct sight of the microphone.

Frequency (Hz)	Medium triangle	Small triangle	Large triangle	Square
GCC-PHAT	full-band	full-band	full-band	full-band
Narrowband MUSIC	1500	3000	1500	1500
Wideband MUSIC	700 – 1700	700 – 3400	700 – 1700	700 – 1700
Dynamic MUSIC	700 – 1700	700 – 3400	700 – 1700	700 – 1700

Table 2 – *Frequency band used for source angle estimation.*

For the second location, location B in contrast, the area between the loudspeaker and the microphone array was relatively flat with dense undergrowth and multiple trees. At both locations, the battery operated PA loudspeaker (MAX P12BT) was placed on the ground to replicate kiwi habitat [19]. The microphone array was raised one metre from the ground. There were also differences in the signal to noise ratio (SNR) between the two locations, with location A having an SNR of 1.6 dB and location B having an SNR of 5 dB, due to mainly the difference in the noise level. The SNR was measured by the average sound power level of the kiwi call and ambient noise which are recorded separately. Since the recordings at location B was collected later in the same evening, it seems possible that the wind may have settled, diurnal birds in the forest stopped rustling, or distant vehicle noise stopped.

Parameters

Each recording was approximately 7 seconds long. For MUSIC and its variants, STFT with Hamming window was applied to the microphone array observation and the expectation operation for calculating the spatial correlation matrix (10) was realised by taking the average across frames. The frame size of STFT was 2048 points with no frame overlap. ***Table 2*** summarises the frequency band that were used for the source angle estimation.

(a) Location A *(b) Location B*

Figure 6 – *Views from each location in Parry Kauri Forest, a typical New Zealand bush used for sound recording and measurement, looking towards the recorder.*

The threshold used in the dynamic MUSIC were determined by

$$th_l = Q_{q_l}(s(t))$$
$$th_\omega = Q_{q_\omega}(P^2(t) - \sigma^2(t)),$$

where $Q_q(\cdot)$ denotes the q-th percentile of data points. 0.65 and 0.75 were heuristically selected for *ql* and q_ω, respectively.

RESULTS AND DISCUSSION

Evaluation metrics

The estimation accuracy of the algorithms tested have been evaluated using two different metrics: the root mean square error (RMSE) and the mean error (ME) defined in (19) and (20), respectively,

$$\mathrm{RMSE} = \sqrt{E[|\hat{\theta}_i - \theta_{true}|^2]}$$
$$\mathrm{ME} = E[|\hat{\theta}_i - \theta_{true}|],$$

where $\hat{\theta}_i$ is the estimated angle of the sound source in the *i*-th dataset (out of 10 recordings) and θ_{true} is its ground truth angle. RMSE is used to measure the deviation of the estimates whereas the ME is a measure of accuracy, and represents how closely the results match the ground truth. The results of the experiments evaluated by these metrics are summarised in ***Table 3 and 4.***

ALGORITHM

Among the four algorithms implemented, GCC-PHAT provided the most accurate results across almost all scenarios (i.e. microphone array configuration and location in the bush). It is likely that one of the known advantages of GCC-PHAT being robust to reverberation [37] has contributed to the results given that the bush environment has been found quite reverberant.

On the other hand, among MUSIC based methods, wideband MUSIC can be seen to be significantly better than narrowband MUSIC and marginally better than dynamic MUSIC in nearly all cases in both accuracy and deviation. It was expected that the wideband MUSIC would perform notably worse than dynamic MUSIC because it would not have any control over what signals were used for localisation. This was not the case; the similarity in performance may have come from the fact that there was little background noise in the recordings, or that any noise was of a similar sound level to the kiwi call and were therefore included by dynamic MUSIC. This would mean that the wideband MUSIC and dynamic MUSIC would effectively be carrying out the same calculations on the same sections of the call, however the dynamic MUSIC would clip the call slightly, meaning that it would use less of it, and be less accurate. Another potential reason for the unexpected result would be the fact that each segment extracted by dynamic MUSIC consisted of only a few frames, which were insufficient to approximate the expectation by averaging frames. Narrowband MUSIC performed much worse than the other two algorithms, with very poor accuracy and deviation. It also does not seem to show any significant improvements with any of the different array geometries and sizes. Overall, it has been proven without a doubt that MUSIC must be used with some modification to be useful for localisation of bird calls in native bush environments.

Microphone array configuration

Among the four microphone array configurations, the small triangle was most accurate for the case of GCC-PHAT, wideband MUSIC, and dynamic MUSIC because the smaller array is able to cover wider frequency range without being affected by the limitation of the spatial Nyquist frequency. This does not affect narrowband MUSIC because narrowband MUSIC uses a single frequency rather than a whole frequency range. It was expected that the small triangle may not be as accurate compared to larger arrays because it has smaller aperture size, i.e. coarse spatial resolution. However, it has appeared that being able to use wider frequency range of the recording is somewhat more important. Our implementation of GCC-PHAT uses a cubic spline interpolation which means that there will be a point at which an increase in size and therefore spatial resolution will result in little difference in localisation performance.

RMSE (°)	Medium triangle	Small triangle	Large triangle	Square
GCC-PHAT	54.47	**4.46**	22.86	7.56
Narrowband MUSIC	66.62	42.35	62.97	73.53
Wideband MUSIC	37.50	10.47	25.07	12.89
Dynamic MUSIC	39.65	10.95	30.39	26.52

Mean Error (°)				
GCC-PHAT	9.18	**3.23**	6.79	5.61
Narrowband MUSIC	30.55	22.45	24.93	19.58
Wideband MUSIC	21.13	5.88	13.71	7.88
Dynamic MUSIC	18.30	6.40	14.50	11.30

Table 3 – *RMSE and ME for each algorithm and microphone array configuration.*

Mean Error (°)	GCC-PHAT	Narrowband MUSIC	Wideband MUSIC	Dynamic MUSIC
Location A	**6.3**	16.1	9.9	11
Location B	**5.7**	40.4	13.3	15

Table 4 – *Effect of location on localisation accuracy.*

Between medium and large triangles, the large triangle performed better than the medium triangle over all four localisation algorithms for both RMSE and ME. This finding implies that the localisation algorithms used in this study were not significantly susceptible to spatial aliasing as long as it only occurs in some of the microphone pairs but not all. This result indicates that the increase in angular resolution does have a positive impact on both the accuracy and deviation of the localisation outcome.

In terms of the shape of the microphone array, as stated in section 4.2, the square and large triangle arrays are directly comparable as half of their microphone pairs are the same size, and both their larger set of pairs breach the spatial sampling theorem at frequencies below the pitch of kiwi call. Overall square performed better than large triangle, with a respective 14.7% and 25.96% decrease of RMSE and ME. It was expected that the square array would perform worse than the triangle, due to the fact that all the lengths in a square are closer in size, meaning those pairs in the square would not have as favourable resolution as those in the triangle. However, it also means that the pairs in the square would cause spatial aliasing at a higher frequency than those in a large triangle, meaning that less data is corrupted by spatial aliasing. It would appear that including some pairs causing spatial aliasing does not severely degrade the localisation performance as they also contribute to increase the spatial resolution. However, too many such pairs naturally cause the benefits to diminish.

Location in the bush

In terms of the effect of acoustics in the bush to the estimation accuracy, there are notable differences in the performance of MUSIC based algorithms in location A compared with location B as seen in ***Table 4.*** Narrowband MUSIC is much more accurate in location A than location B. Wideband and dynamic MUSIC also show better results in location A, but the difference is less than that of the narrowband MUSIC. In contrast, GCC-PHAT is somewhat unaffected by the change in locations showing only less than one degree difference in the ME between the locations. Importantly, this shows how MUSIC based methods can be affected by larger amount of reverberation (i.e. longer reverberation time) and the absence of prominent direct sound (i.e. low DRR) as opposed to GCC-PHAT being largely unaffected by similar changes.

Interestingly GCC-PHAT shows the opposite trend to MUSIC, i.e. the estimation is slightly more accurate in location B than in location A. This would be caused by the lower SNR of the recordings at location A, however the effect seems to be marginal so that it would not be as crucial as that of reverberation and low DRR.

CONCLUSION

Four sound source localisation algorithms have been tested in order to explore the performance of the methods for use in the native New Zealand bush to localise bird calls. A physical recording system, which included various microphone array configurations, was used for field recordings in the bush. A loudspeaker was used to replicate calls of the North Island brown kiwis.

Among the algorithms tested, the GCC-PHAT using multiple microphone pairs has proven as the method that provides the most accurate localisation. The wideband MUSIC and dynamic MUSIC were also valid, however they were less reliable than GCC-PHAT across many situations. Dynamic MUSIC has been proven to have an advantage over all other methods when the power of the target sound is much larger than other coherent signals.

Various microphone array configurations have also been compared which proved that the small triangle was much more accurate than those with the larger sizes. This configuration being used with the GCC-PHAT has achieved a RMSE of 4.46° and ME of 3.23°. The results also imply that the square shape may perform better than triangle when their sizes are similar.

The GCC-PHAT was the least susceptible to the changes of source location. However, future study is needed as the test was limited to the two locations.

ACKNOWLEDGEMENT

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(references on pg.40)

FERRYMEAD BRIDGE REPLACEMENT PROJECT – CONSTRUCTION VIBRATION

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ABSTRACT

The replacement of the Ferrymead Bridge in Christchurch involved the installation of piles over a 15 month period. Due to the close proximity of both residential and commercial neighbours and as the substantial pile casings were to be driven in by a heavy impact and vibratory hammer, the resulting vibration received at the nearby buildings was identified as a potential impact at an early stage in the project. Specialist vibration advice was provided to the project team, and throughout the works the vibration issues were dealt with collaboratively and collectively by the client; designers; contractors; and the vibration advisors. This paper details the vibration assessment; monitoring; and management procedures that were used. The collaborative approach towards the management of vibration resulted in a number of positive outcomes for the project, including minimal complaints; no disruption to local businesses; and no lost construction time due to vibration issues.

INTRODUCTION

Before the February 2011 earthquake, the Ferrymead Bridge was in the process of being strengthened and widened but as liquefaction occurred in the riverbed and significant damage was caused to the existing structure during the Canterbury earthquakes, Christchurch City Council (CCC) decided to replace the bridge with a structure which fully met the current standards. This involved larger and deeper piles. The Ferrymead Bridge Replacement Project is currently in progress and is jointly funded by the CCC and the NZ Transport Agency, with HEB Construction Limited as the main contractor on the project, and design work undertaken by Opus International Consultants. Completion is due in mid-2015.

Extensive and detailed geotechnical investigations were undertaken in the locations of the new bridge piles and these showed that the underlying rock is extremely variable with some layers being weak. Thus the six 1.1m diameter abutment piles and the four 2.4m diameter pier piles for the new bridge are founded using a maximum length of pile of 31m to enable adequate support. This piling work was expected to last approximately 15 months.

Figure 1 illustrates the location of the bridge and the surrounding area. The area to the west of the new bridge is predominantly commercial, with some mixed/residential use buildings. One of these commercial premises, Chiptech, designs and builds electronic devices and is located approximately 160m from the bridge. A large number of residential dwellings are located to the south east. To the north east of the bridge is the Mount Pleasant yacht club and boat sheds, together with Penfold's Cob Cottage (a heritage-listed structure) and the Mount Pleasant telephone exchange.

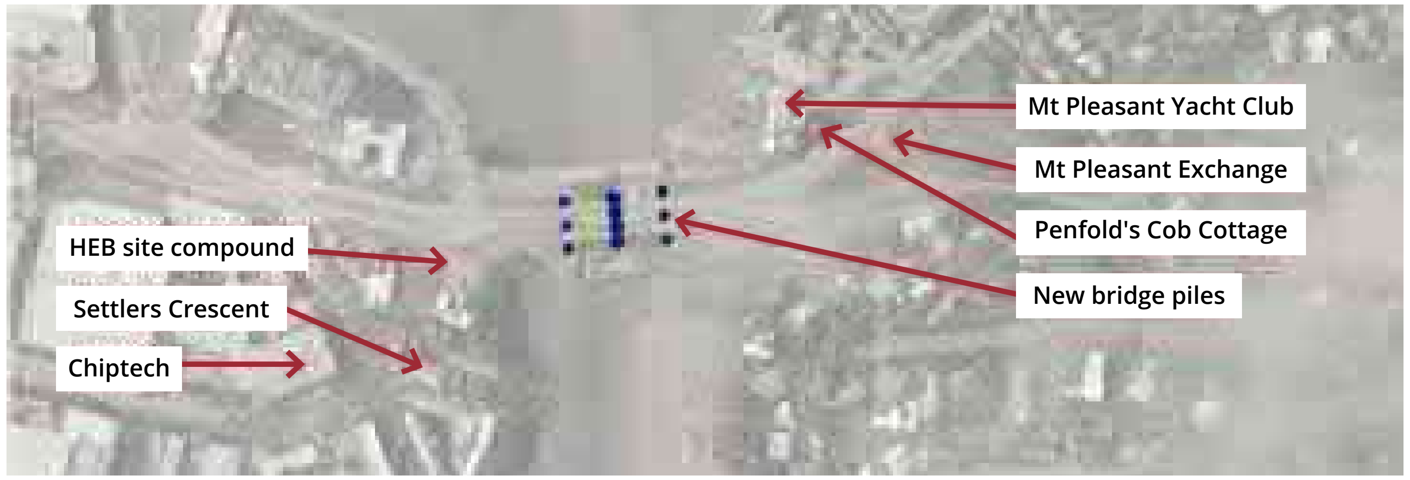

Figure 1 – Ferrymead Bridge and surrounding area

Due to the close proximity of these neighbours and as the substantial pile casings were to be driven in by a heavy impact and vibratory hammer, the resulting vibration received at the nearby buildings was identified as a potential impact at an early stage in the project. Specialist vibration advice was provided to the project team by URS, and throughout the works the vibration issues discussed below were dealt with collectively by the client (CCC), designers (Opus) and contractors (HEB) with a collaborative approach.

This paper details the vibration assessment, monitoring and management procedures that were used for this project.

INITIAL ASSESSMENT

Prior to the piling work commencing the potential impacts of the piling vibration were assessed. Accurately predicting vibration from construction works is not straightforward as it is often difficult to quantify the energy transmitted from the pile into the ground and, most significantly, the propagation of the energy through the ground. The level and frequency content of the vibration that is propagated through the ground will depend on the dynamic properties of the soils, rocks etc. and any layering in the ground structure. Therefore, without detailed knowledge of the propagation characteristics of the ground, empirical methods [1] were used to predict the level of vibration at a range of distances from the works. These predictions are typically conservative, i.e. an over-estimation of the actual vibration levels is made. The cost of this conservatism is generally less than the cost of more complex investigations (which would involve trial measurements of piling or another vibration source on the site) or the costs associated with halting the work once in progress.

Vibration criteria for the project were determined to assess annoyance, building damage (cosmetic or structural) and damage to underground services ***(Table 1)***. These are in terms of a peak particle velocity (ppv).

A comparison was made of the predicted levels with these criteria ***(Figure 2)***. This showed that the vibration would affect numerous buildings and showed a significant risk associated with the piling work. There was a risk of cosmetic damage (e.g. plaster cracking) to sixteen buildings and risk of disturbance from vibration in fifty-six buildings.

To assess	Threshold	Vibration level
Annoyance	Perception of daytime vibration in residential buildings	1 mm/s ppv
	Perception of daytime vibration in commercial buildings	2 mm/s ppv
Building damage	Cosmetic damage to structures	5 mm/s ppv
	Minor structural damage	15 mm/s ppv
Damage to underground services	Damage to plastic pipes	50 mm/s ppv

Table 1 – *Vibration criteria*

To manage this risk the project team decided to under-take the following:

- Inspection of buildings in the industrial area to identify any sensitive occupancy.
- Further assessment of the effects of vibration on Penfold's Cob Cottage.
- Further consultation with the neighbours of the project by means of a public meeting to describe the works and the likely effects of vibration. This included a comparison of the expected vibration from the construction works in comparison with that which occurred during the Canterbury earthquakes.
- Pre-and post-work building condition surveys so that any effects of the piling vibration on the structures could be identified from any pre-existing damage.
- Inclusion of the piling vibration within the Construction Noise and Vibration Management Plan for the project. This incorporated:
  - › Additional public liaison to forewarn neighbours of at the start of piling activity.
  - › A vibration monitoring programme.

The vibration sensitivity of Chiptech (Settlers Crescent) was identified during the public meeting. As a result of this new information, the risk of disruption to their manufacturing process was subsequently mini-mised by the installation of anti-vibration mounts under the printed circuit board assembly line.

MONITORING

As part of the vibration management regime described above, monitoring was conducted to confirm the predictions made in the initial assessment. Vibration measurements were undertaken on the following occasions:

1. For the first abutment pile on each side of the bridge and the first pier pile:
   - › as the casing was driven through the sediment layer,
   - › as the rock chisel and grab was first operated within the casing, and
   - › as the casing was driven into the rock layer/to depth.
2. During the installation of additional staging piling.
3. When a different piling technique or equipment was used.
4. As the result of any complaints regarding vibration.

Forty-eight measurements were made between May 2013 and May 2014 covering the different piles and phases of piling, and at a range of locations, including:

- 3 Ferrymead Terrace
- 4/36 Settlers Crescent
- 5/36 Settlers Crescent

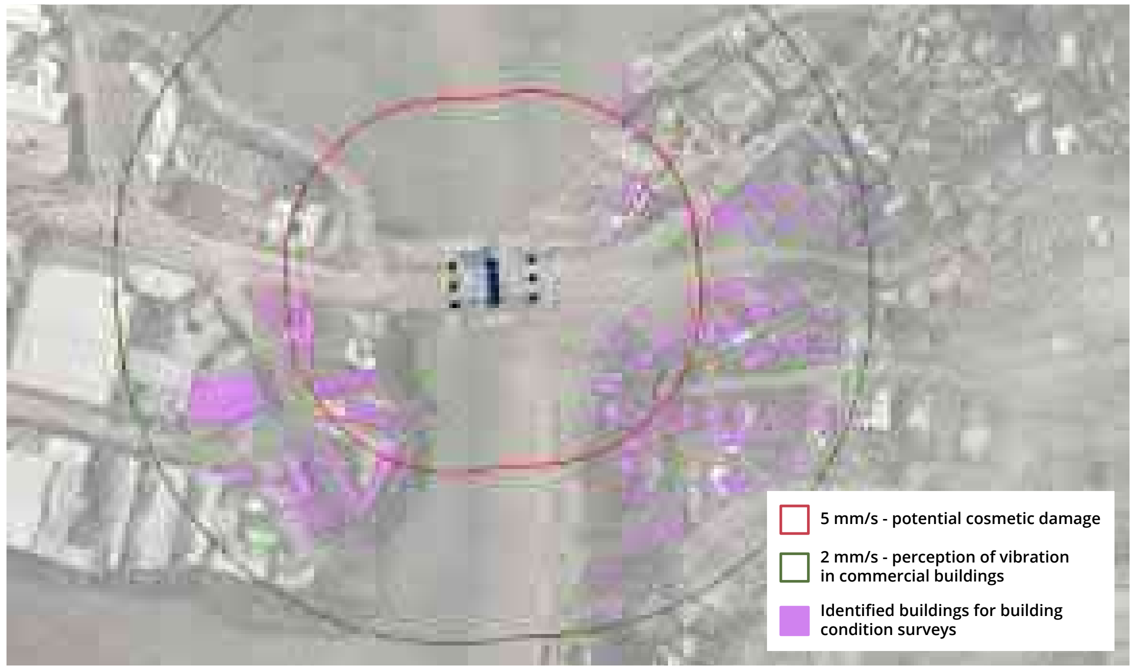

Figure 2 – *Predicted vibration levels and buildings to be surveyed*

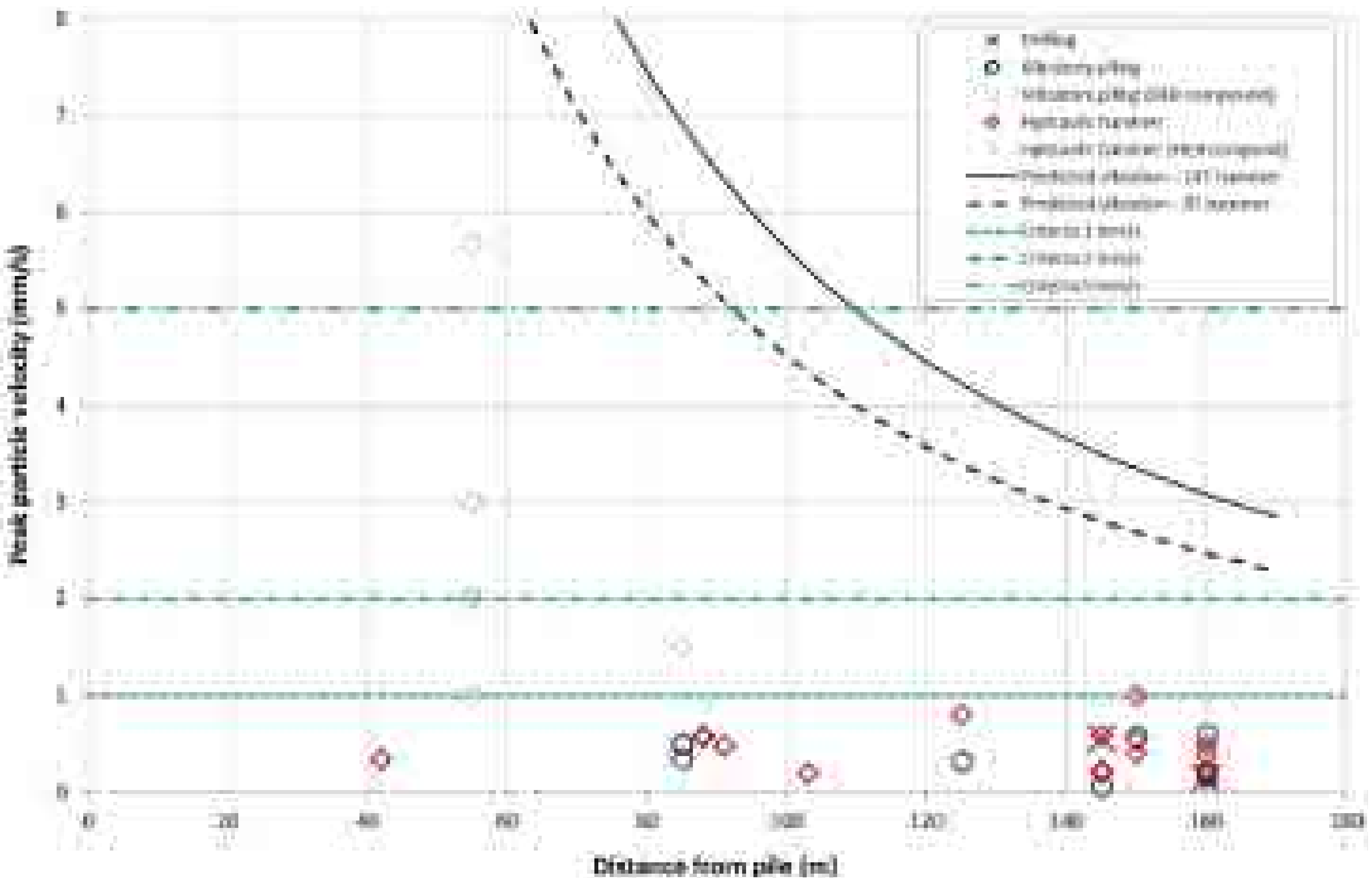

Figure 3 – Measured and predicted vibration levels

- Above the nearest underground services
- Chiptech, 11a Settlers Crescent
- HEB site compound (reference position, which is not subject to any vibration limits)
- Mount Pleasant Telephone Exchange
- Mount Pleasant Yacht Club
- Sand Bar, 1070 Ferry Road

The results are summarised in ***Figure 3*** which plots the ppv of the ground vibration at the receivers listed above against the distance from the piling works. The reference position measurements are identified as grey circles and grey diamonds.

The maximum vibration level measured at a residential or commercial property was 1.0 mm/s ppv in the Chiptech building, at a distance of approximately 150m from hydraulic impact piling on the west side of the bridge.

Also presented in this graph as black lines are the predicted levels of vibration both for the 14 T hammer envisaged before work commenced (and hence used in the vibration assessment) plus the 9 T hammer actually used on site. These predictions are higher than the levels measured, reflecting the conservatism of the prediction method.

The location and building-use specific project criteria are also included as green lines and demonstrate that vibration levels were below the criteria on all occasions. From the initial predictions it had been expected there would be widespread exceedance of the criteria.

The measurements show the vibration may have been felt in neighbouring residential properties (as the threshold for perception is approximately 0.3 mm/s ppv in such environments) but generally not at such a level to cause annoyance (1 mm/s ppv). There was negligible risk of cosmetic (or structural) building damage as a result of the piling works as the measured vibration levels are less than 5 mm/s ppv. These findings are consistent with the subjective observations received from the occupants of the Chiptech building.

One complaint was received from a residential dwelling in Settlers Crescent during the vibratory piling of the staging on the west side of the new bridge. The levels were monitored and assessed when the same works occurred again. It was concluded that although the vibration from these piling works may have been perceptible in the property, significant annoyance should not have been caused and there was no risk of building damage. No further complaints were received from the occupant.

A second complaint was received from a local commercial property regarding some minor building damage. Using the pre-work condition survey, the project team were able to demonstrate that this damage pre-existed and therefore not caused by the bridge construction works.

CONCLUSIONS

The collaborative and proactive approach taken by the project team towards the management of construction vibration on the bridge replacement works has resulted in the following positive outcomes:

- effective consultation and engagement with neighbours,
- minimal complaints,
- no disruption to local businesses, e.g. Chiptech,
- no lost construction time due to vibration issues, and
- the value of pre-work building condition surveys has been illustrated.

An alternative approach to the management of construction vibration is a purely reactive process whereby the upfront vibration assessment and building condition survey work is avoided. This approach initially saves cost and time but with the risk that the works are slowed or even halted, together with associated delays and potentially significant cost, as a result of a complaint.

Without the consultation and engagement with the project's neighbours, no prior knowledge would have been gained of sensitive locations such as Chiptech (which was missed during the initial inspection of buildings in the industrial area) and residents would be more sensitive and anxious as a result of the vibration if they had not been forewarned. Once vibration can be felt, people tend to be concerned about damage to their properties, although the levels at which perception and damage occur are considerably different. These vibration levels were presented and explained during the public meeting, thus minimising concerns.

ACKNOWLEDGEMENTS

The authors wish to thank Christchurch City Council and HEB Construction for their permission to publish this paper.

(references on pg.41)

Photo (above) – *Ferry mead bridge under construction*
Credit: Beckerfraser Photos

IMPROVING THE ACCURACY OF NOISE COMPLIANCE MONITORING OF WIND FARMS

Chris Turnbull

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Original peer-reviewed paper

ABSTRACT

The most common method for measuring the noise from an operational wind farm is long term logging and correlation of noise level with wind speed. The noise at residences from wind farms is often lower than the noise from other sources and this presents significant challenges in noise compliance monitoring. Further, there has been a focus on the accuracy of noise compliance monitoring in the media and this highlights the need for the most accurate method of compliance monitoring to be adopted. This presentation describes a number of techniques recently used to monitor noise compliance at various wind farms to overcome the inherent challenges of separating wind farm noise from the noise of other sources.

INTRODUCTION

The noise criteria for wind farms in Australia are determined as the higher of a base level (either 35 dB(A) or 40 dB(A)) or 5 dB(A) above the measured background noise level (EPA SA, 2003) (EPA SA, 2009) (Standards Australia, 2010) (Standards New Zealand, 2010). The background noise level is determined by measuring the noise at residences in 10 minute intervals and pairing the L_{A90} noise level in each ten minute interval with the hub height wind speed. A line of best fit through the data is drawn and this is taken as the background noise level at each wind speed. ***Figure 1*** shows an example of the data pairs, the line of best fit and a line 5 dB(A) above the background noise level (representing the objective criteria).

There is a general perception in the community that following construction, the noise from a wind farm can be easily measured and compared against the objective criteria without any averaging of data or analysis of variation (Madigan JJ 2015). However, measuring the noise from an operating wind farm in the presence of varying ambient noise is not a simple task. This is demonstrated by the example of ***Figure 2*** and ***Figure 3***, which show the L_{Aeq} and L_{Amax} respectively for the same noise logging period as ***Figure 1***. The objective criteria derived from ***Figure 1*** have been shown for context.

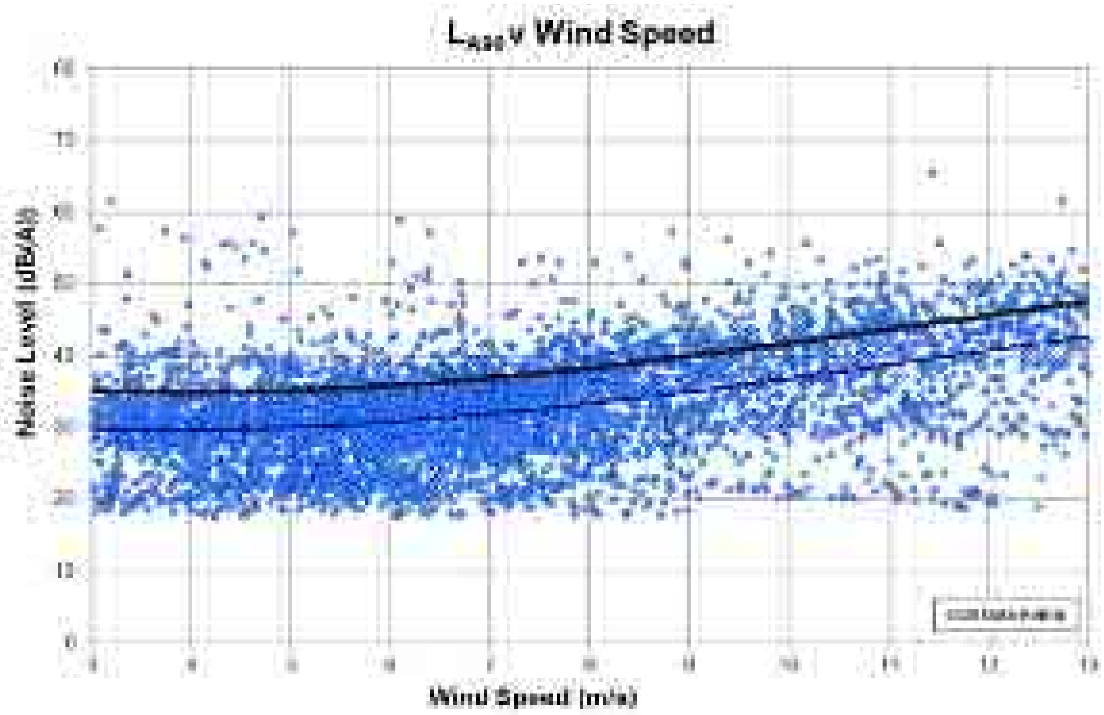

Figure 1 *– Correlation of wind speed with background noise (L_{A90}) and derivation of criteria*

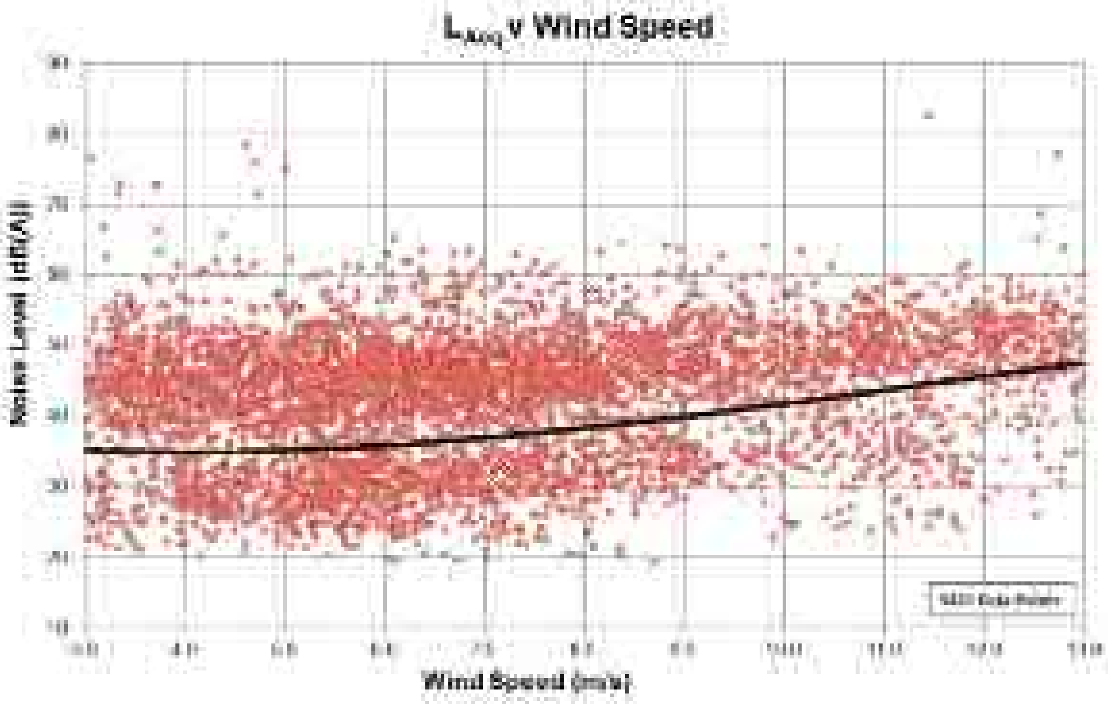

Figure 2 *– Correlation of wind speed with L_{Aeq}*

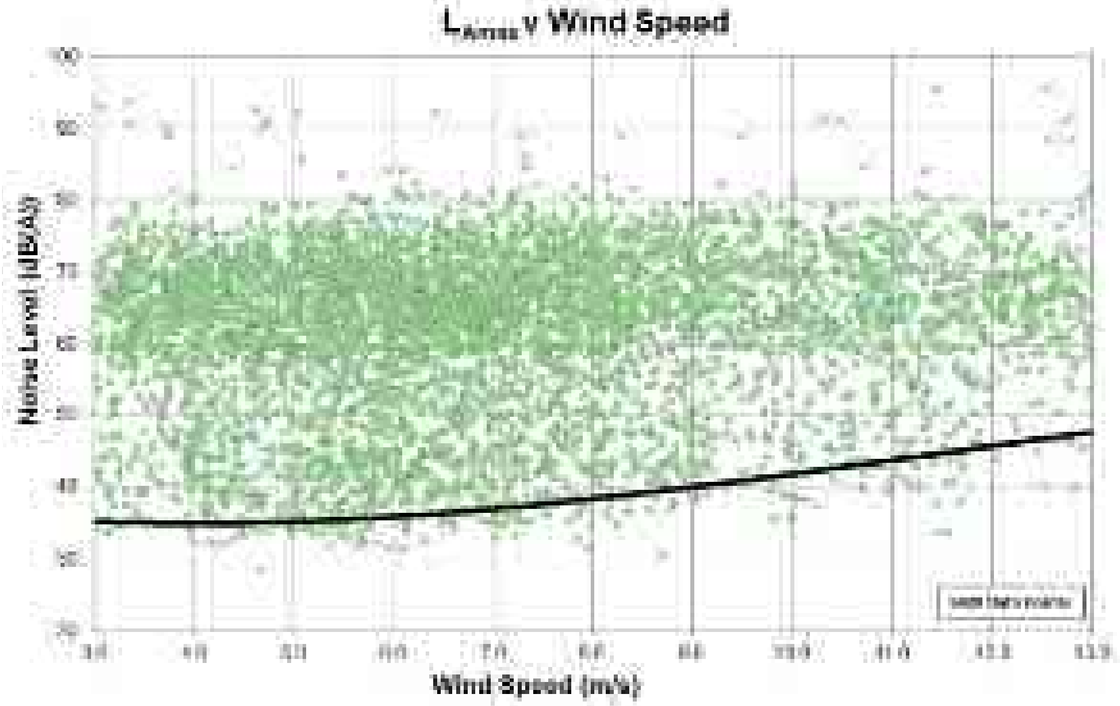

Figure 3 – *Correlation of wind speed with L_{Amax}*

The figures show that the ambient noise in the environment varies greatly and is often higher than objective wind farm criteria. Therefore, the measured noise during wind farm operation will be a combination of ambient noise and wind farm noise and cannot be attributed entirely to the wind farm. On/off testing is often referenced as a defining test where the identification is difficult but even when on/off testing is conducted, the accuracy is dependent on level of ambient noise at the time of the test and the assumption that the ambient noise does not change from one test period to the next. In these circumstances, the most common method of wind farm compliance measurements is to repeat the pre-construction logging and compare the pre-construction levels with the post-construction levels. Any increase is attributed the operation of the wind farm.

Given the potential for, and implications of, false results, techniques have been used to improve the accuracy of wind farm compliance measurements at sensitive receptors. These techniques include:

- extensive data collection;
- the use of frequency analysis;
- the comparison of upwind and downwind data points.

In addition to these techniques at sensitive receptors, which are described in detail below, conducting measurements between the wind farm and the residences provides an opportunity to improve the wind farm to ambient noise ratio. This technique involves predicting the noise at an intermediate location and comparing the measured level with the predicted level. Where the measured level is no greater than the predicted level, the noise model can be considered to be verified. Therefore if the noise model predicts that the criteria are achieved at residences and the noise model is verified, it can be inferred that the noise at residences complies with the criteria. However, the method relies on the stakeholders accepting that a prediction model can form part of a compliance checking procedure.

DATA REQUIREMENTS

When comparing the operational noise with pre-construction noise, it is important to have sufficient data to account for any natural variation in ambient noise. This is particularly the case when the data are required to be separated into wind directions or day and night periods. ***Table 1*** lists the minimum recommended data requirements for the various Standards and Guidelines used in Australia.

When the data collected during the night time period are separated, the requirements of the various Standards and Guidelines result in less than 1000 data points. To provide an indication of the variation in ambient noise for a given size of dataset, six weeks of data were separated into datasets of 250, 1000 and 1400 data points. ***Figure 4*** shows the datasets of 250 points, ***Figure 5*** shows the datasets of 1000 points and ***Figure 6*** shows the datasets of 1400 points.

With 250 point datasets, the variation is 15 dB(A) at 12m/s. That is, if the lower dataset had been recorded before the wind farm had been constructed and the higher dataset had been recorded after the wind farm had been constructed the data would imply exceedance by 10 dB(A), without any contribution from the wind farm. Conversely, if the higher dataset had been recorded before the wind farm had been constructed and the lower dataset had been recorded after the wind farm had been constructed the reliance on the data would allow the windfarm to contribute noise well above the background noise level without showing any non-compliance. With 1000 point datasets, the variation is 10 dB(A) at 14m/s and with the 1440 point datasets the maximum variation is 6 dB(A) at 14m/s.

It is noted that in some circumstances, where separation of the data into subsets (such as wind direction) is required, the separation has the potential to minimise the spread of data, although this has not been found to be the general case in practice.

The example demonstrates the importance of extensive datasets and highlights the risk of creating subsets of data, which result in inadequate sized datasets. The practice, which is becoming more common, of collecting six weeks of data (approximately 6,000 data points) appears to provide an appropriate amount of data.

Standard or Guideline	Minimum recommended number of data points	
	Background noise measurements	Compliance noise measurements
(EPA SA, 2003)	2000	2000 downwind
(EPA SA, 2009)	2000 with 500 downwind	2000 with 500 downwind
(Standards Australia, 2010)	2000	2000
(Standards New Zealand, 2010)	1440	1440

Table 1 – *Data requirements of Guidelines and Standards used in Australia. Note: (Standards New Zealand, 2010) requires the number of measurements made to be sufficient to allow dependable correlations to be obtained between the sound levels and the wind speed.*

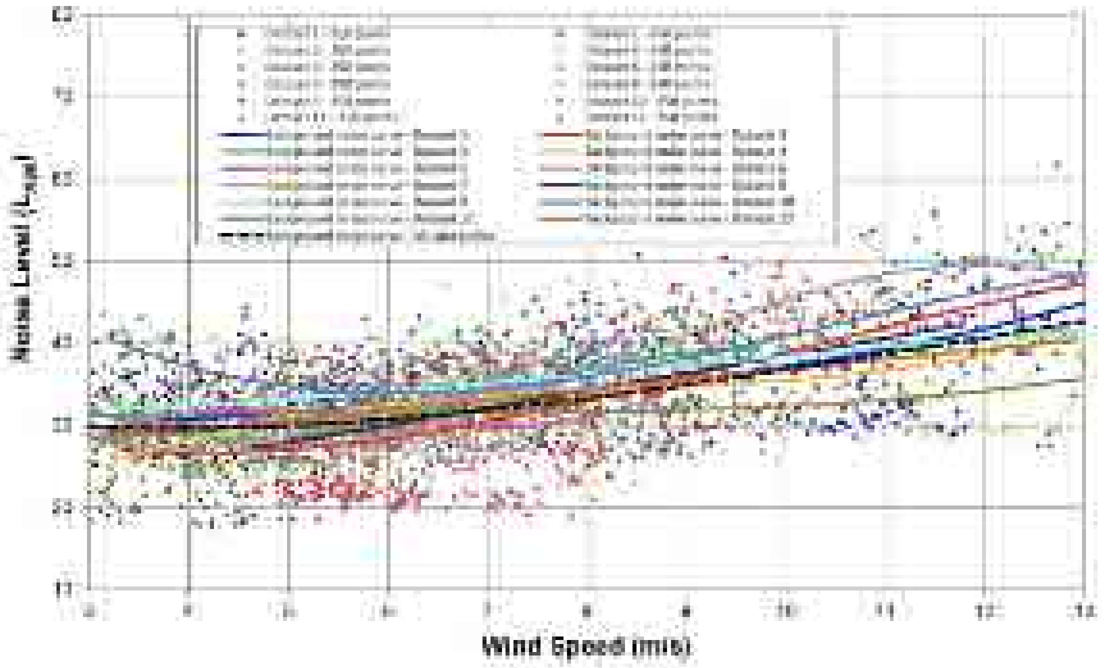

Figure 4 – *Correlation of wind speed with L_{A90} divided into 250 point datasets.*

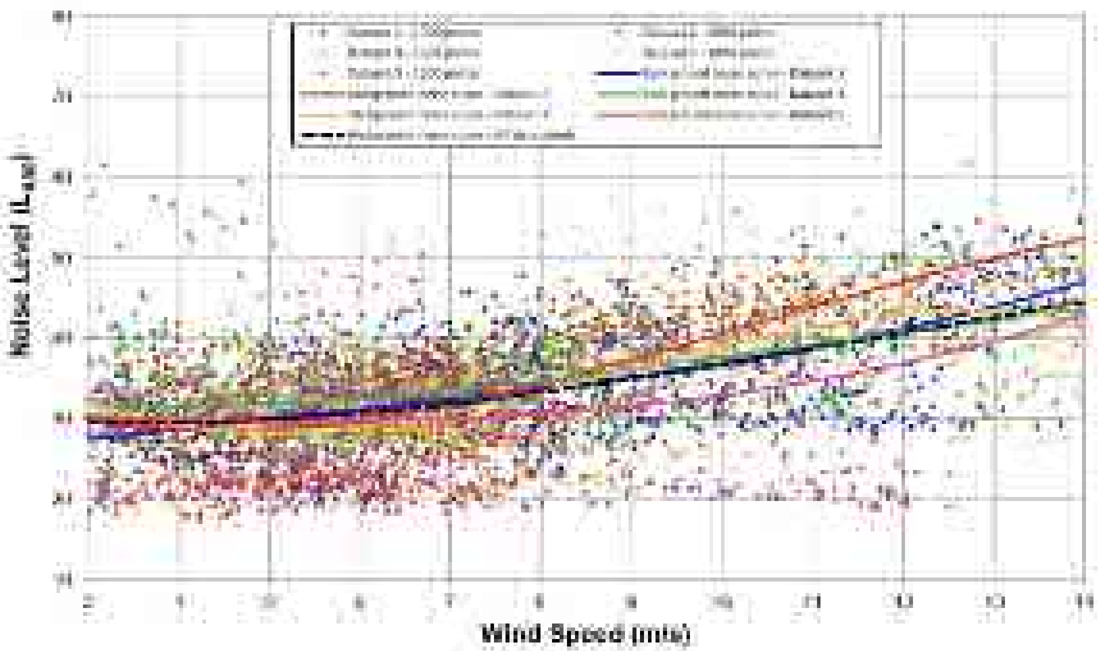

Figure 5 – *Correlation of wind speed with L_{A90} divided into 1000 point datasets.*

FREQUENCY ANALYSIS

The noise emitted from wind turbines is broadband, with content in the low, mid and high frequencies. However, at residential setback distances, typically in the order of one to two kilometres, the high frequency noise is attenuated by air absorption, leaving no significant contribution in the 2000Hz octave band or above. In contrast to the lack of high frequency content from wind turbines at residences, the ambient noise often has significant high frequency content. This is particularly the case where insects are present. This difference in frequency content provides the opportunity to apply a low pass filter to remove all high frequency content without removing any significant contribution from the wind farm. ***Figure 7*** shows the noise in the vicinity of an operating wind farm with and without the high frequency content removed. ***Figure 7*** demonstrates the potential to reduce the extraneous noise from the measurement of noise from an operational wind farm with a reduction of approximately 6 dB(A). This difference could easily amount to the difference between a wind farm being considered compliant and non-compliant.

COMPARISON OF UPWIND AND DOWNWIND DATA POINTS

Over the past 15 years, the technique of background noise monitoring has continually improved. This includes an increase in the amount of data collected, the use of sound level meters with lower noise floors and improvement in wind shields to minimise noise from wind on the microphone. Therefore, for wind farms approved in recent years, there is generally reasonable background noise data available, which were collected prior to construction. However, for wind farms approved and constructed previously, there is often little data or the data have been collected prior to the improved techniques being implemented. In circumstances where limited ambient noise data are available it is even more difficult to separate the component of wind turbine noise from the noise produced by other sources.

At residential setback distances, the noise from a wind farm is greater when the wind is in a downwind direction (in the direction from turbines to residence) than an upwind direction.

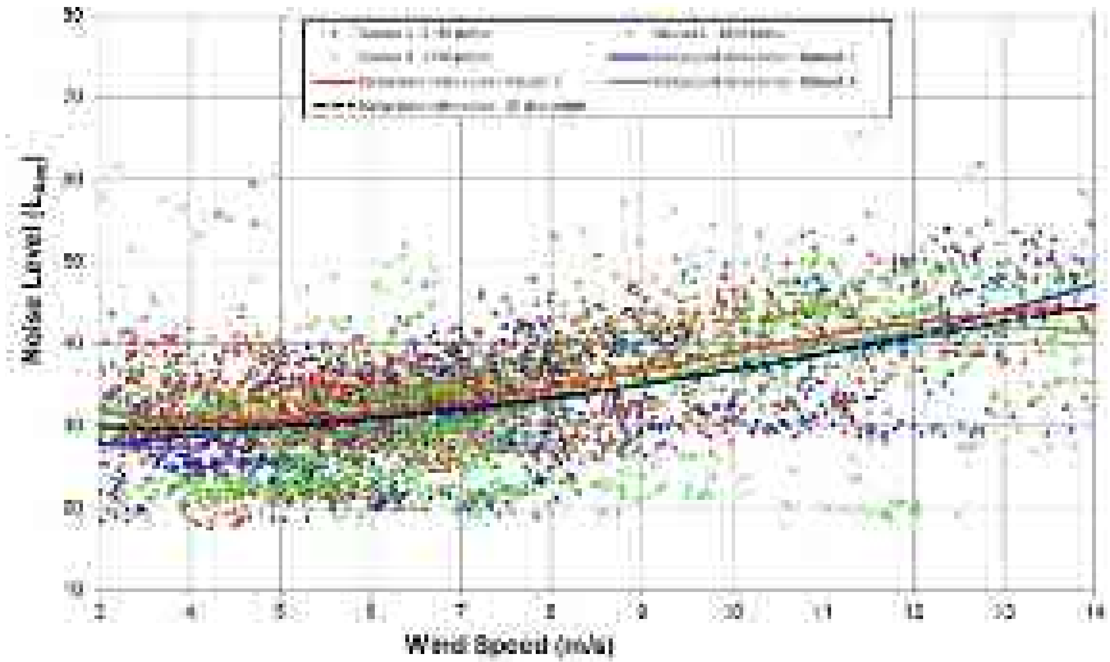

Figure 6 – *Correlation of wind speed with L_{A90} divided into 1440 point datasets*

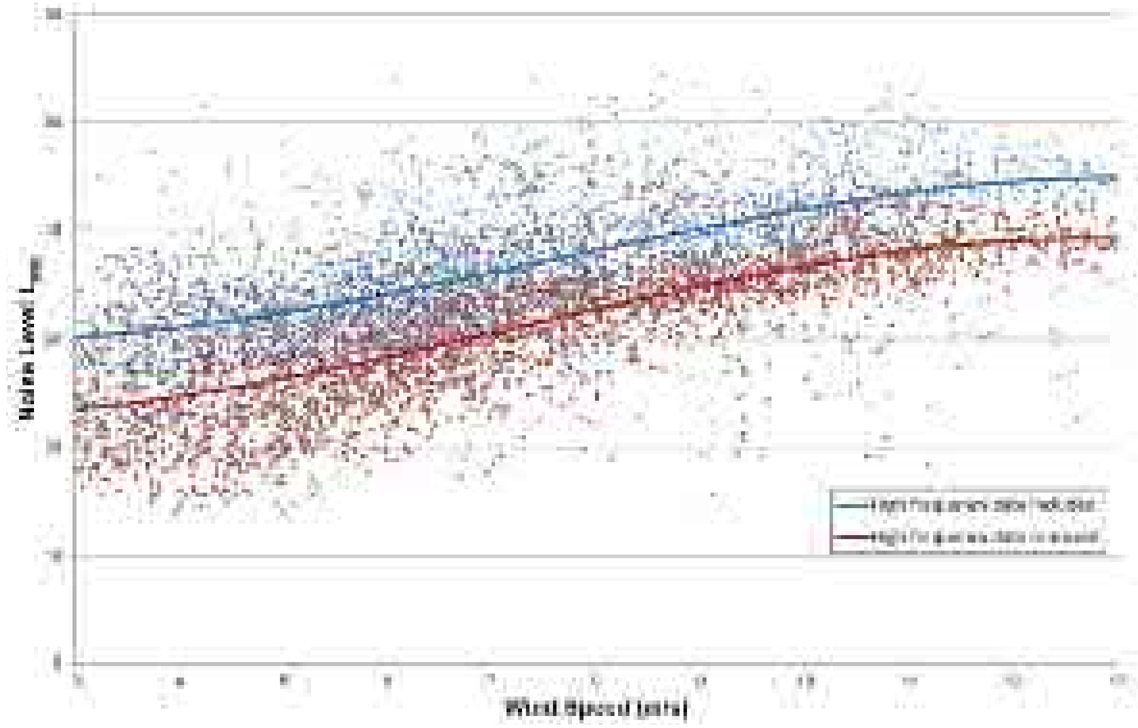

Figure 7 – *Noise in the vicinity of an operating wind farm with and without high frequency content.*

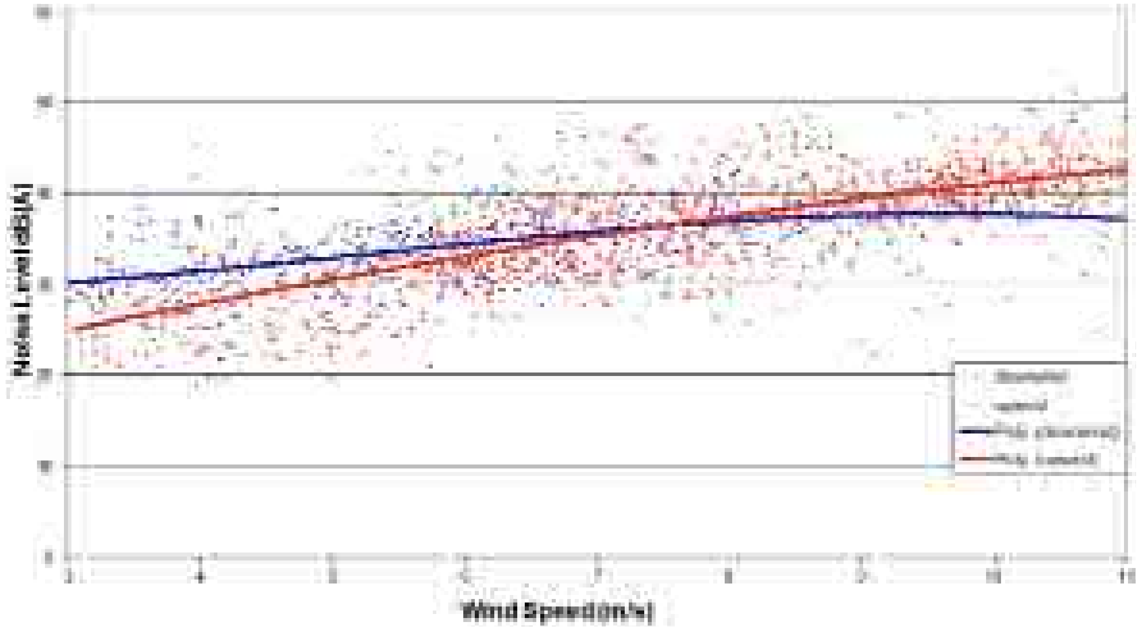

Figure 8 – *Comparison of upwind and downwind data to estimate wind farm noise contribution.*

The difference is generally considered to be in the order of 10 dB(A) (Institute of Acoustics, 2013). Therefore, one method of providing an indication of the noise contribution from a wind farm is to compare the noise collected in an upwind direction with data collected in a downwind direction. Where there is no significant difference at a particular wind speed, it is reasonable to assume that the wind farm is not contributing significantly to the overall noise level. Conversely, if there is a significant difference, the contribution of noise from the wind farm can be estimated from the difference.

Figure 8 shows an example of compliance noise data collected at a location where there were no suitable pre-construction background noise data. If all noise had been attributed to the wind farm at high wind speeds, the result would indicate non-compliance with the criterion of 35 dB(A). However when the upwind and downwind data are compared, it indicates that the wind farm makes no significant contribution at high wind speeds.

When using this technique, it is important to collect as much data as practical because separation into sectors reduces the amount of data available and, depending on prevailing winds, can result in very few data points. It is also important to consider that the ambient noise might be different for different wind directions. This might occur at locations where the wind in a certain direction is shielded by topography, resulting in lower noise from wind in trees.

CONCLUSION

The noise from a wind farm, when measured at residences, is often lower than the ambient noise from other sources. In these circumstances, it is important to consider techniques to separate the wind farm noise from the noise from the other sources. These techniques include:

- extensive data collection;
- the use of frequency analysis;
- the comparison of upwind and downwind data points.

While these techniques can assist in understanding the contribution of wind turbine noise to the overall noise level, there is still no single method which accurately separates wind turbine noise from other noise in all circumstances. Rather, it is expected that a combination of these methods will need to be employed depending on the specific circumstances and the important factor for stakeholders is to understand that such methods will need to be utilised in some scenarios.

ACKNOWLEDGEMENTS

I would like to acknowledge the support of the wind farm operators in assisting with the provision of the wind data required for the analysis.

(references on pg.41)

HOW SOUND IS YOUR ACOUSTICS KNOWLEDGE?

1. In a sentence or two describe what signal processing refers to?

2. What is being referred to when discussing 'Cetacean Acoustics'?

3. What is Statistical Energy Analysis (SEA)?

4. **True or False?**
   Strings and membranes belong to the category of structures where the stiffness is due to external compressions.

5. **True or False?**
   A common typical definition of noise is unwanted sound.

6. What is sonoluminescence?

7. **True or False?** Unlike octave band and one third octave band filters, which are proportional (or constant-percentage) bandwidth filters, a fast Fourier transform (FFT) analyser is essentially a set of fixed-bandwidth filters.

8. What is the ISO 3740 standard series used for?

9. What does the following formula relate to:
   $M_{com} = Mo + g1 + 20 \log[C/(C+Ci)]$?

10. **True or False?**
    Animals rely upon their acoustic and vibrational senses and abilities to detect the presence of both predators and prey and to communicate with members of the same species.

(answers on pg.43)

Photo (left) – Sound wave transformer
www.crazytoys.co.uk

IN THE ENVIRONMENT COURT

CABLE BAY WINES LIMITED AND
MOTUKAHA INVESTMENTS LIMITED - ***Appellants***

AUCKLAND COUNCIL - ***Respondent***

www.rma.co.nz | [2019] NZEnvC 029, 25p, [109] paras, 22 February 2019

Summary of Facts

The appellants owned ten hectares of land near the western end of Waiheke Island at 12 Nick Johnson Drive, Church Bay. Recently, a second restaurant, large kitchen and outdoor facilities were added and undertaken without consent. The appellants applied for retrospective consent in April 2017, but this was rejected by Council commissioners. The neighbouring rural residential properties alleged that shortly after the consent refusal, the appellants further expanded the illegal activities and the Council reacted by bringing enforcement proceedings.

In decision [2018] NZEnvC 226 the Court confirmed that consent had been refused for the outdoor hospitality activities and in the enforcement proceedings the Court would make orders for the physical removal of facilities and the control of outdoor patrons. The Court then went on to note the indication of possible consent for the restaurant and kitchen, subject to satisfactory conditions being finalised. In the first interim decision the Court found the effects on the environment were considerably more than minor particularly in relation to noise effects and it set the acoustic witnesses and planners the task of refining the draft conditions of consent to meet the needs of avoiding or acceptably mitigating the adverse acoustic effects and general loss of amenity being suffered by the neighbouring property owners.

The greatest issue was the effective management of noise, including low frequency noise from The Verandah restaurant and bar area and from activities on the lawn. Since at least 2014 the scale and intensity of those activities had increased significantly from what was legally authorised, with increased noise effects near the site which had affected the amenity and health of several local residents. The Court noted that plan noise limits would not achieve the required plan outcomes for an activity of the scale and intensity applied for, particularly when special audible characteristics and cumulative effects were taken into account.

Subsequently, general agreement on draft conditions by parties indicated support for a much more limited consent than applied for. The Court detailed restrictions on outdoor activities and tentatively anticipated being satisfied that the adverse effects would be no greater than those experienced in the lawfully existing environment. However, the Court reiterated that approval would only be forthcoming if the conditions were manageable and capable of reasonable monitoring and enforcement. The Court directed parties to lodge the anticipated report on the collaborative work by the acoustic engineers and urged them to reach agreement where possible.

Court Held

Court refused part of the original application relating to outdoor hospitality, excepting those areas where consent conditions were to be confirmed for the Verandah Restaurant, alfresco dining adjacent to the original restaurant, and the holding of outdoor wedding functions on a delineated area of lawn. *Costs reserved.*

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2019 UPCOMING EVENTS

08 - 13 September

Aachen, Germany

23rd International Congress on Acoustics

13 - 17 September

Detmold, Germany

International Symposium on Musical Acoustics

15 - 17 September

Amsterdam, Netherlands

International Symposium on Room Acoustics

30 November - 06 December

San Diego, California

178th Meeting of the Acoustical Society of America

QUIZ ANSWERS

1. Signal processing refers to the acquisition, storage, display and generation of signals as well as the extraction of information from signals and the re-encoding of information. As such signal processing in some form or another is an essential element in the practise of all aspects of acoustics.

2. Cetacean relates to the study of acoustics for any member of an entirely aquatic group of marine mammals commonly known as whales, dolphins, and porpoises. The ancient Greeks recognised that cetaceans breathe air, give birth to live young, produce milk, and have hair all features of mammals.

3. Statistical energy analysis (SEA) is a method for predicting the transmission of sound and vibration through complex structural acoustic systems. The aim of SEA is to use power flows as a means for estimate the responses of complex systems.

4. False.

5. True.

6. Sonoluminescence is luminescence excited in a substance by the passage of sound waves through it *(i.e. sound waves not only give rise to self-steepening and shock waves but may even become the driving agent to the emission of light).*

7. True.

8. The International Organization for Standardization (ISO) has published a series of international standards, the ISO 3740 series which is used to describes several methods for determining the sound power levels of noise sources.

9. Capacitance Correction. The combined level sensitivity of the microphone and preamplifier. where *Mo* is the open-circuit sensitivity of the microphone (dB re 1V/PA), g1 is the gain of the preamplifier (dB), *C* is the capacitance of the microphone, *Ci* is the input capacitance of the preamplifier.

10. True.