Special Section

Transactions

Editor: Ernest Edmonds

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Transactions welcomes submissions concerning topics listed in the journal's current "Calls for Papers" (see <leonardo.info/isast/spec.projects/spec.projects.html>). In addition, *Transactions* calls for papers in the following areas:

- The integration of practice and theory in art-led research
- Contributions to science and technology from art practice
- Scientific methods used within art practice.

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Rainwire: Environmental Sonification of Rainfall

Dave Burraston, Centre for Research in Complex Systems, Charles Sturt University (CSU), School of Information Technology, Building S15 Panorama Ave. Bathurst NSW 2795, Australia, and The WIRED Lab (www.wiredlab.org). E-mail: <dave@wiredlab.org>.

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Abstract

The *Rainwire* project forms part of an art/science initiative to investigate environmental sonification of land-based natural rainfall using large-scale long wire instruments.

Introductory Background

A central environmental and climatic problem of 21st-century science is the protection of freshwater resources. Availability of freshwater for human consumption, agriculture and industry is both a national and international concern. The main source of freshwater is rainfall, and underground water sources are also ultimately dependent on this same source. The complex problem of understanding natural rainfall events is vital for informed sustainable land management and fundamental research in complex systems, climatology and meteorology. *Rainwire* aims to be at the forefront of environmental sonification by demonstrating fundamentally different and novel approaches for research in land-based rainfall through an interdisciplinary art/science project. Key algorithms and techniques will be investigated for extracting the sound signatures of different rainfall patterns from vibrations induced on long wire instrument spans.

The long wire instruments in this project were originally developed for sonic art by Australian composer Alan Lamb from disused sections of telegraph wires. Lamb developed new construction methods for these large-scale installations by using high-tensile fencing wire constructed in single or multiple spans across an area of the landscape, usually in rural locations [1,2].

Spans of long wire instrument can range from tens to hundreds of metres, up to a total multispan length of several kilometres or more, usually supported by poles or attached to very large rocks. Spatial arrangements have often been in the form of a single line, angled lines, parallel lines, radial lines from a central point to compass points (e.g. NESW), although many types of configurations are possible. Construction of long wire instruments has taken place on flat land, across gulleys, down hillsides, over complex terrain and sections of water.

Long wire spans are classed as *suspended cables*, which exhibit a complex variety of non-linear dynamical behaviours and are an *archetypal* complex system with applications in many fields of engineering, e.g. mechanical, civil, electrical, ocean and space [3,4,5]. Complex systems is an emerging multidisciplinary science developing new ways of researching large, highly intricate, dynamical systems in diverse areas such as biology, physics, social networks, sociotechnological systems, socio-ecological systems, economics and the environment [6,7].

Suspended cables have significant research interest; in particular the investigation with stochastic/random excitation and rain-wind induced vibration is a vital area where new studies and results are important.

Rainfall event properties are key requirements for research in environmental processes, agricultural processes, flood management, rainfall simulation and modelling, built environment and urban drainage [8]. Research in understanding and detecting global and regional environmental change requires these rain event properties to be analysed in high resolution at the sub-daily level.

Environmental Sonification

Sonification is the presentation of data or information via sound, and the most well-known scientific instruments in this field are the Geiger counter and sonar [9,10]. Generally, methods of sonification of environmental data for scientific application to date have been based on digital sound generation from *data*, as opposed to analogue means. In such projects the phenomena under examination have been sampled to create data sets that are subsequently ‘mapped’ in an arbitrary way to sound synthesis engine parameters that produce audio output [11]. However, the more the data is mediated, the less direct the relationships are between the stimuli and responses. The resultant audio in typical sonification bears a somewhat arbitrary relationship to the source phenomena, because the process is abstracted through the creation of a data set. Sonification from real world physical actions, as opposed to being mediated via electronic sound synthesis mapping, can be seen in an early example by Galileo Galilei in the formation of the law of falling bodies [12]. In this experiment Galileo attached bells to an inclined plane in order to make his discovery.

Long wire instruments fundamentally differ from existing data-based sonification processes and rainfall measurement devices by generating sonic events directly from rainfall patterns in real time through induced cable vibrations. Piezo transducers are used to convert mechanical vibration into audio signals for recording, measurement and analysis, effectively sonifying the rainfall patterns. A proof of concept sonification of a rainfall event using a long wire instrument is available online at WIRED Lab [13]. This sonification demonstrates the feasibility of the system to capture rainfall events and convert them to sonic information without any data abstraction. Additional recordings of rainfall events that were captured purely for artistic and music composition are also available online at WIRED Lab.

Environmental sonification and earlier artistic composition of rain-induced sounds with long wire instruments have resulted in a wide range of unique, audibly human recognisable features. Such features appear highly connected with rainfall event properties, e.g. duration, intensity, event profile and drop size. These unique sound properties can take the form of high-frequency crackles, sizzling, high-to-low frequency swept zaps similar to the sounds produced by a sound synthesizer, metallic pings, strange percussion and clicks. All of these features exhibit dynamic amplitude and spectral characteristics depending on the rain type and environmental conditions.

Future Work

Acoustic analysis using Digital Signal Processing (DSP) techniques has been successfully applied to rainfall measurement at sea using underwater acoustics for decades. Initial research was conducted during World War II, when rainfall was discovered to impact on military sonar. Techniques were subsequently developed for Acoustic Rain Gauges (ARG) to identify rainfall events through unique frequency spectrum characteristics between 1 and 50kHz [14,15]. The unique characteristics of rainfall impacting water are created by the initial impact and the subsequent formation of an underwater bubble for certain raindrop sizes. These variable drop impacts produce different frequency signatures as a result of this unique mechanism, which can be used to deduce important rainfall parameters.

Detection, analysis and quantification for *Rainwire* is inspired from the underwater acoustics methodology used for ARGs. However, it should be noted that the physics of the two processes are completely different, resulting in different spectral responses and signatures for rain-induced vibrations on wire/suspended cables compared to water surfaces. Future research will therefore require the detection of new spectral signatures associated with long wire systems, as well as the identification of any potential background noise or tones and identification of any potential limitations. As with underwater acoustics, background sounds will need to be identified. A land-based long wire instrument can potentially be subject to a number of unwanted sounds through the sensitive piezo transducers such as insect collisions on the wire; spiders, birds (both collisions and perching); tree and leaf debris; wind noise and Aeolian tones; man-made interference sounds such as electric cattle fences and radio/ transmission beacons.

Converting rain sonifications into their frequency domain representation will use a vastly improved DSP method over the Fast Fourier Transforms (FFT) in current use. This new FFT technique is based on prime number theory and called the Prime number Discrete Fourier Transform (PDFT) and it vastly simplifies the time-intensive calculations involved. The PDFT has the potential to drastically reduce signal processing and cost requirements by up to 95% [16].

Following this initial research on obtaining spectral signatures for different drop sizes, future work will aim to:

i) Quantify wind-induced Aeolian tones and background noises

ii) Develop acoustic inversion algorithm empirically to match rain gauge level measurements and obtain a drop size distribution and rainfall rate.

Once an acoustic inversion procedure is identified, it is then proposed to apply the results to three main issues:

i) Relationship between rainfall rate (R) and radar reflectivity (Z), the main result desired by most researchers using rainfall radar

ii) Classification of rainfall types as convective (heavier rainfall with shorter space and timescales) or stratiform (light widespread rainfall)

iii) Temporal analysis of rainfall to show intra-minute variability. Few other rain gauges can show this type of detail, which is a unique advantage of the high resolution of acoustic techniques. This may enable the discrimination of rapid onset or cessation of subcells within rainfall events.

The complex systems methodologies will encompass techniques from nonlinear time series analysis which are recently being used in rainfall research [17], although not on acoustic data.

Complexity measures can provide a measure of a system's organisational complexity (structure, regularity, symmetry and pattern). Complexity measures are an important complementary addition to quantifying degrees of randomness, because measures of randomness cannot measure the structure or organisation within a system.

There is an explosive increase in the use of sensors in the environment, ranging from ubiquitous computing to agricultural and environmental monitoring. A future plan for the long wire instrument is for it to be completely remotely monitored and controlled, and Wireless Sensor Networks (WSN) are a key enabling technology. WSN consist of low-cost miniature sensors capable of remotely sensing data and sending it to a base station for aggregation and processing [18].

Conclusions

An initial investigation into the environmental sonification of natural rainfall events for the purposes of sonic art and music have formed the impetus for preliminary scientific investigations. *Rainwire* has the potential to contribute to the complex systems research knowledge base in the following key areas:

i) Extending the scope and methodology of rainfall detection, classification and quantification through the application of signal processing and new/ existing complexity measures

ii) Extending knowledge in the nonlinear dynamics of random excitation and fluid interactions with suspended cables

iii) Publically available datasets of high resolution long wire instrument rainfall sonifications for explorations of physical theory and pattern recognition.

It is anticipated that the *Rainwire* project will enable a bidirectional influence between the artistic and scientific investigations of long wire instruments.

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