AN ANALYSIS OF UNCERTAINTY AND STATISTICS OF HIGH DYNAMIC RANGE ACOUSTIC SIGNALS

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Abstract

In this paper, a number of large dynamic range acoustic signals statistics has been presented based on continuous wavelet transform. Some typical examples from battlefield acoustics and from musical acoustics are considered. Therefore, a specialized platform and a measuring microphone with the required features are used in field experiments. The characteristic acoustic environment signature and background noise features for some concrete setup are described. Possible directions for using these technics for signal statistics analysis for retrieving useful information, based on Shannon entropy, are outlined. The datasets consisting of the raw data and metadata from bell ringing and gunfire, and noise recordings are estimated. The wavelet transform was of particular importance here, as it provides both constant-bandwidth analysis that correlates with sound perception and optimal resolution. The discussed problems by means of continuous wavelet transform (CWT) and decomposition (or Shannon) entropy are approached. The results can be used in various areas of acoustics and electrodynamics.

1. INTRODUCTION

In the recent years, some application of modern acoustic methods in interdisciplinary fields and discovery of the difficulties when signal processing and storing of high dynamic range acoustic data, such as music, noise of natural phenomena, battlefield acoustic, and others was regarded [1, 2, 3].

Many acoustic data from field experiments have been collected since 2008 at different sites.

Wavelet analysis offers a way to process this acoustic data collection and it provides possibility to made interesting considerations about their characteristics.

The analysis based on Shannon entropy have been powerful and useful in determining the noise influence.

The aim is presenting one direction for using technics for signal statistics analysis for retrieving useful information, based on Shannon entropy and wavelet processing.

2. SHANNON ENTROPY PROPERTIES IN ACOUSTIC DATA PROCESSING

In Donoho et all work, [4] is discussed some of the lessons of harmonic analysis in the XX century and the authors made this interesting possible connection between the compression, and not only compression, of real data, concerns random, and the deterministic objects analysis following Tikhomirov's words:

"our vast mathematical world" is itself divided into two parts, as into two kingdoms. Deterministic phenomena are investigated in one part, and random phenomena in the other.

To Kolmogorov fell the lot of being a trailblazer in both kingdoms, a discoverer in their many unexplored regions he put forth a grandiose programme for a simultaneous and parallel study of the complexity of deterministic phenomena and the uncertainty of random phenomena, and the experience of practically all his creative biography was concentrated in this programme.

From the beginning of this programme, the illusory nature of setting limits between the world of order and the world of chance revealed itself" [4,5].

The ideas of entropy of the signal or signal uncertainty and its measure (bits per signal units) was defined in communication theory.

In Stratonovich work, [6] Shannon entropy for a continuous random variable with p.d.f. $p(\xi)$ is defined as an expectation:

$$H_{\xi} = \mathrm{E}[p(\xi)] == -\int_{\mathbf{X}} p(\xi)\ln p(\xi)\,d\xi$$

or $H_{\xi} = -\int_{\mathbf{X}-\boldsymbol{\Lambda}-\boldsymbol{\Lambda}_0} \ln\left(\frac{dP}{d\nu}\right) P(d\xi)$, in case $\nu_0(\xi) = d\nu/d\xi = 1.$

In other side Shannon entropy can be defined with Kullback–Leibler divergence as:

$$\mathrm{H}(\boldsymbol{X}) = \mathrm{E}[\mathrm{I}_{\boldsymbol{X}}(x)] = \log(N) - D_{KL}(p_{\boldsymbol{X}}(x) \parallel P_U(\boldsymbol{X})).$$

So, H(***X***) is the number of bits which would have to be transmitted to identify ***X*** from *N* equally likely possibilities, less the relative entropy of the uniform distribution on the random variates of ***X***, $P_U(\boldsymbol{X})$ from the true distribution P(***X***).

The *relative entropy* or *Kullback–Leibler distance* between two probability mass functions *p(x)* and *q(x)* is defined, [7] as

$$D_{KL}(p \parallel q) = \sum_{x \in \mathcal{X}} p \log \frac{p}{q} = E_P \log \frac{p(X)}{q(X)}$$

Some useful properties of Kullback–Leibler divergence was demonstrated also in R. Angelova-Slavova's works [8, 9].

The known analogy with quantum systems, is in Sanchis-Alepuz paper [10] where the Shannon's information entropy defined by:

$$Su = -\int \mathcal{P}(\mathrm{r}) \ln \mathcal{P}(\mathrm{r}) d\mathrm{r}$$

Probability distribution function $\mathcal{P}(\mathrm{r})$ similarly to electronic density distribution here is normalizing the square of the displacement field of a given acoustic level

$$\mathcal{P}(\mathrm{r}) = |u(\mathrm{r})|^2 / \int |u(\mathrm{r})|^2 d\mathrm{r},$$

and this quantity gives the uncertainty of the localization of sound in acoustics problems.

3. WAVELET ANALYSIS AND SHANNON ENTROPY

The wavelet transform is used to decompose a mixture of signals and noise, into components at different resolutions and make some conclusions about noise features.

It is known that the finer scales in the continuous wavelet transform (CWT) gives a higher-fidelity signal analysis. It can be better describe oscillations or localize signal transients, with the CWT than with the discrete wavelet transforms.

One regard to wavelets, which can be viewed as an information processing technique can be found in Oliveira's work, [11] where the concept of wavelet mutual information between a signal and an analyzing wavelet is introduced.

The Shannon entropy of some orthogonal wavelets, like Daubechies, Symmlets, Coiflets, that cannot be described by analytical expressions can be found by using the so-called two-scale relationship of a multiresolution analysis.

In [11] a few simple discrete signals were analyzed in order to gain insight into the information theory approach for multiresolution analysis. One possible method for measurement of entropy of discrete signal wavelet packets, [12,13] is expressed as:

$$\mathrm{WPE_N} = -\sum p_{j,n} \log p_{j,n}$$

where $\mathrm{p_{j,n}} = \mathrm{E_{j,n}} / \mathrm{E_{tot}}$ - relative energy for scale j,

$$\mathrm{E_{j,n}} = \sum_{\mathrm{k}} \left| \mathrm{d_{j,n}}(k) \right|^2, \ \mathrm{E_{tot}} = \sum_{\mathrm{n}} \mathrm{E_{j,n}}$$

$$\mathrm{p_{j,n}} = \frac{\sum_k \left| 2^{\frac{\mathrm{j}}{2}} \int_{-\infty}^{\infty} \mathrm{s(t)} \, \psi_{\mathrm{n}} (2^{-\mathrm{j}} \mathrm{t} - \mathrm{k}) \mathrm{dt} \right|^2}{\sum_{\mathrm{n}} \mathrm{E_{j,n}}}$$

$\mathrm{s(t)}$ is original signal,

j, n, k represents the scale, band, and surge parameter, respectively.

Equation for $\mathrm{WPE_N}$ uses the Shannon method to calculate WPE. The N notation in $\mathrm{WPE_N}$ is used to denote the level of decomposition used in Wavelet packet decomposition.

The idea is that the accuracy of the selected wavelet basis is higher when the entropy is small.

4. WAVELET ANALYSIS AND SHANNON ENTROPY OF EXPERIMENTAL ACOUSTIC DATA

The interaction of the acoustic wave with objects, such as the ground, obstacles, the effects of reverberations, first reflections, absorption, interference and diffraction, turbulence etc. will change the registered sound pictures in real setups, [14,17].

The sound picture and noise level is varying in accordance of type of concrete space: close or free space, in dependence of source and receiver points placement. They change depending on the local parameters as temperature, wind speed and direction, air pressure and humidity etc.

In the next it was made the analysis of a set of experimental data and it was found the wavelet entropies of the different sound records.

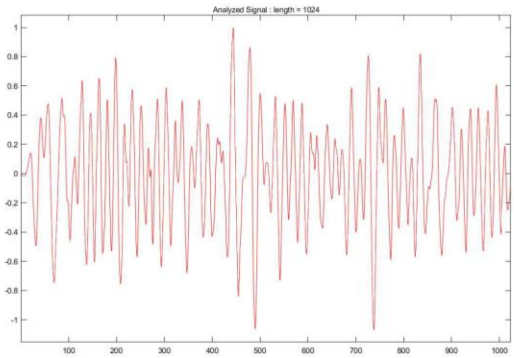
First it was regarded the unique bell sounds in close space. The signals, see project Bell [1,3] denoted as Melnik2-1220 AD, was registered inside the hall in National Historical Museum in Sofia. In the figures 1a) and b) was shown some bell strike waveforms (ringing) in time.

Zoomed fragment of last bell strike in the time scale are shown in Fig.1b).

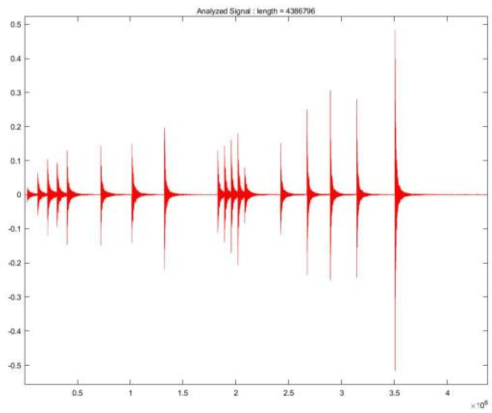
Second signal, illustrated on a Fig.2 consist a parts from time signal from the first blast from 122 mm 2S1 howitzer ("Gvozdika ") see [15], where in a) is shown the signal captured from two blasts from the two howitzers ("Salvo"), in b) the first from two blasts, 1024 samples.

And in third, record of noise of hailstone strikes, plus noise of auto alarms was regarded, see fig.3a), and zoomed part in Fig.3 b). The conditions for hail dropping strikes in concrete urban environments was: 20 May 2013, see [16].

This raw data was exported in MatLab and here were determined Shannon entropy coefficients for the wavelet tree for Daubechies3 wavelet level 3. Fig. 4 shows wavelet packets for three parts of bel ringing waveform (Fig. 1).



a)



b)

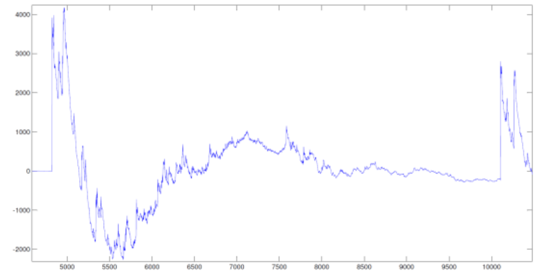
Figure 1. Waveforms of unique bell stroke (XIII cent.), a) ringing, on the b) it was separated only last bell ring

The wavelet packet entropies for concrete bel ringing signals in hall, totally 3 examples (noise, noise and part of ring, ring) were calculated and some results are shown in table 1. In table is shown entropies for the simulated noise with normal and uniform distribution.

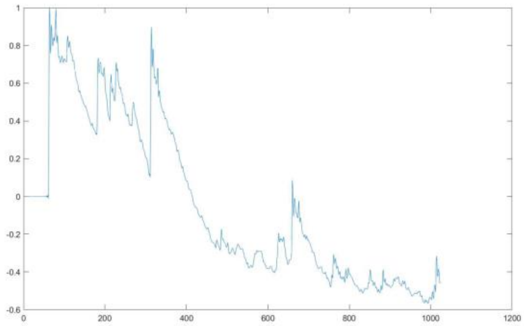
Analogically wavelet packet entropies for the signals from blast fig. 2 and hail strikes fig. 3 were calculated. Part of results is shown in table 3.

From wavelet packet entropies presented in table 1,2 can be seen that for noise and for signal with noise the coefficients of Shannon entropy ShE(1,1) has higher values, than other situations.

Then the proportion of ShE(1,0) and ShE(1,1), and ShE(j,0) and ShE(j,1) i.e. entropy of approximation coefficients to detail coefficients may be parameter for noise discrimination.

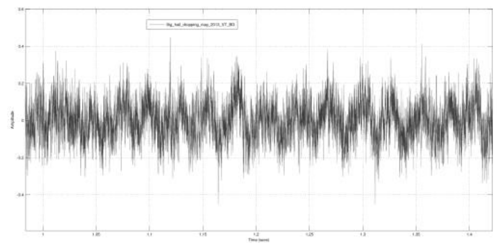


a)

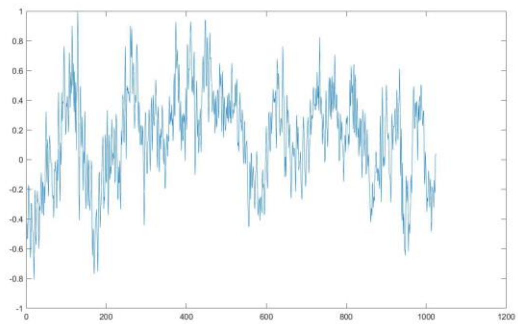


b)

Figure 2. Parts from time signal from the first blast from 122 mm 2S1 howitzer, a) "Salvo", b), the first from two blasts

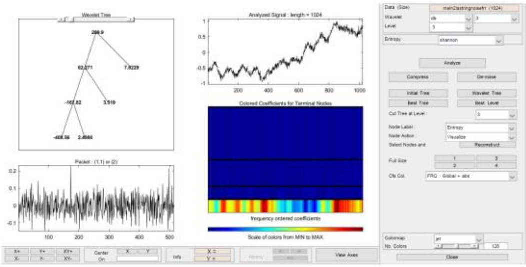


a)

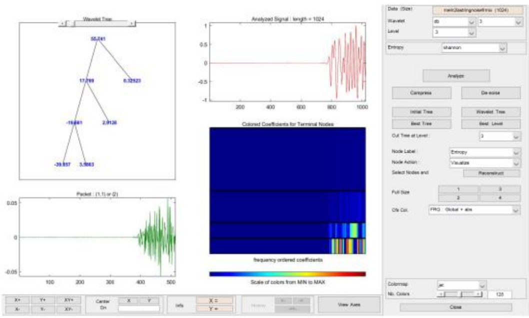


b)

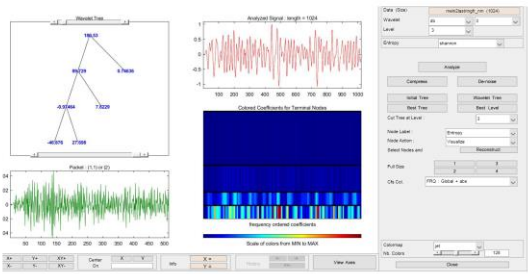
Figure 3. a)-Part of waveform of hail strikes, 0.4sec, in V. Tarnovo, BG, urban environments, 20 May 2013, b) 1024 samples of hail strikes - zoom part of a), Fs=65536 Hz



a)



b)



c)

Figure 4. Calculated wavelet packets and Shannon entropies for three cases: a-noise, b-noise and c-ring, see. fig 1 the last ring, (Daubechies db3, level 3).

Table 1

s name (1024 samples)	ShE(0,0)	ShE(1,0)	ShE(1,1)
Noise	289.9	62.271	7.823
Ring_Noise	55.741	17.769	0.32523
Ring	180.53	89.729	0.74636
Uniform distr simulation	220.2	79.51	79.273
Norm distr simulation	141.85	71.464	68.755

Table 2

s name (1024 samples)	ShE(0,0)	ShE(1,0)	ShE(1,1)
Front of blast artil	248.93	119.26	0.77904
Hail2013	186.35	105.22	19.441
Uniform distr simulation	220.2	79.51	79.273
Norm distr simulation	141.85	71.464	68.755

In audio fingerprinting the background noise is one of degradation factors like as pitching, equalization, analog to digital conversion, audio coders etc. When the purpose is automatically recognizing the type of sound recording Papaodysseus [18] and Roussopoulos [19], proposed recognition system of musical recordings in the presence of noise. The main idea in this works is the assumption of existing of invariant characteristics in time – frequency domain, which are independent of distortion and the system employs a set of mathematical characteristics, extracted from a musical recording, whose determination was based on human perception.

In the other side if the purpose is automatically recognizing the type of location from which the signal is received it can be applied data mining methods like it was presented in [20].

5. CONCLUSION AND FUTURE RESEARCH

As it shown proportion of entropy of approximation coefficients to detail coefficients in entropy of discrete signal wavelet packets may be one parameter for noise discrimination.

The obtained results show acceptable accuracy in many real acoustic situations. It was demonstrated that wavelet processing and Shannon entropy was appropriate to analysis the characteristics of acoustic signals.

The future work will be related to their application in aerial acoustics, in interdisciplinary fields such as, study of noise from natural phenomena, ecology, battlefield acoustics and others.

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