Features of time-frequency analysis visualization of large dynamic range signals

Tihomir Trifonov[1], Ivan Simeonov[2] and Rosen Dzhakov[3]

Abstract – **In this paper practical time-frequency analysis of large dynamic range signals is made. The acoustic signals from unique Bulgarian bells recorded by PULSE 12 data acquisition hardware are analyzed.**

The mechanical and acoustical properties of these objects are discussed and their features are determined. Some specific techniques of visualization are proposed.

Keywords – **time-frequency analysis, acoustic signal visualization, conformal map**

I. Introduction

At work on the project about research of the valuable Bulgarian bells the database was created, in which almost all characteristics of the bells were included [1]. Database includes acoustical records, obtained via unique measurement set. The used measurement and processing methods can be implemented to the other purposes.

The bell is a complicated sound source with a very wide frequency range and an unique dynamic range of the transmitted signal. Its spectrum contains infrasound, sound and ultrasound partials. The dynamic range is very large too and it cannot be detected entirely by human ear whose dynamic range of perception is about 120dB. The best all over the world measurement set with a corresponding measurement microphone at this moment was used because of this [2]. For example, this set is able to process the signal without distortions with dynamic range up to 160dB.

The most modern processing methods and integrated system of computer mathematics MatLab are used [3]. The features of the source and the raw records require this way of measurement [4].

In this paper we propose a new method of presentation of some transformations (Fourier Transform and Wavelet Transform for example). Wavelet Transform gives the improvement for analysis and reception via conversion of 2D signal into pseudo 3D signal. Conform transformation improves these possibilities in addition. We introduce "sound print" as analog of the "fingerprint", used in the criminology and biometrics. The detection and classification of the transmitted object becomes easily. This way the methods of biometric iris recognition can be used for process automation.

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II. Method of "soundprint" visualization

A. Wavelet transform applications

Every signal (or function of time) φ(t), can be described by

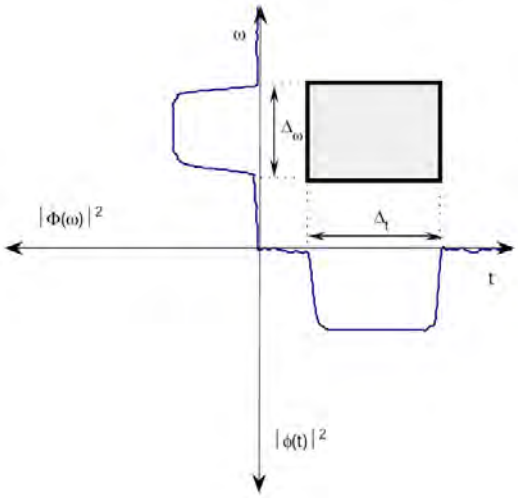


Fig. 1 Localization characteristics of $\varphi(t)$

interval Δ_t in the time axis and interval Δ_ω, in frequency which are including 90% of his energy, concentrated around center of mass of functions $|\varphi(t)|^2$ and $|\Phi(\omega)|^2$. The modulation on this function is translation of the rectangle across axis ω, while the scaling of function (her contraction or

Fig. 2. The disposition of unique bells, denoted as **Melnik1** -1270AD and **Melnik2**-1220 AD, in the National Historical Museum in Sofia.

stretching) changes the rectangle proportions.

In this case, the function φ(t) can be represented as rectangle on the plane $Ot\omega$, as shown in fig. 1.

Unlike to Fourier transform - FT and Short time fourier transform – STFT, wavelet transform will alters the rectangle type for analysis according to the frequency, area of rectangle will stay constant. An illustration of local properties of wavelets in frequency area is shown on figure 3. This is a kind of analyze where, the relation $\omega_0/2\Delta_\omega$ is constant or the quality factor Q is equal. The time-frequency window area stay $4\Delta_t\Delta_\omega$ for a different scales, where Δ_m^2 и Δ_ω^2 are the second central moments on the functions $\psi(t)$ and $\Psi(\omega)$.

More precisely, suppose that $a \in \mathbb{R}^+, b \in \mathbb{R}$, or (a,b) determine one point in right-half plane, then the continuous wavelet transform (CWT) of a continuous, square-integrable function is expressed by:

$$CWT_f(a,b) = \langle f(t), \psi_{a,b} f(t) \rangle = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t)\, \psi^*\left(\frac{t-b}{a}\right) dt, \quad (1)$$

where < , > denotes the inner product.

The wavelet transform of a one-dimensional signal is a two-dimensional time-scale joint representation, [7]. So the resolution of identity must be satisfied, that is expressed as

$$f(t) = \frac{1}{C_\psi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} CWT_f(a,b) \frac{1}{\sqrt{|a|}} \psi\left(\frac{t-b}{a}\right) db \frac{da}{|a|^2}, \quad (2)$$

where,

$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}} \psi\left(\frac{t-b}{a}\right)$ is basis that satisfy the conditions of admissibility (the mean value equal to zero), regularity (has exponential decay, so that its first low order moments are equal to zero), and orthogonality, see fig. 3,

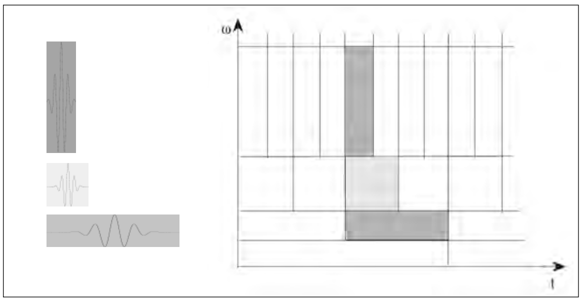


Fig. 3 Wavelet basis functions $\Psi_{a,b}(t)$, and time-frequency plane image, Continuous Wavelet Transform – CWT

$C_\psi = \int_{-\infty}^{\infty} \frac{|\hat{\Psi}(\omega)|^2}{|\omega|} d\omega < \infty$ - the admissibility constant,
$a = 2^k$ − scale parameter, k = 0,1,2, ...,
b – time shift parameter.

B. Experimental set-up

An experimental set-up was realized to record the sound of unique bells in the National Historical Museum, Sofia, [4,5]. Theese objects denoted as **Melnik2**-1220 AD. and **Melnik1** - 1270AD are shown in Fig.2 [2]. The measuring microphone 4193 Brüel&Kjær and Data Acquisition Unit 3560B Brüel&Kjær [2] is illustrated in Fig.4.

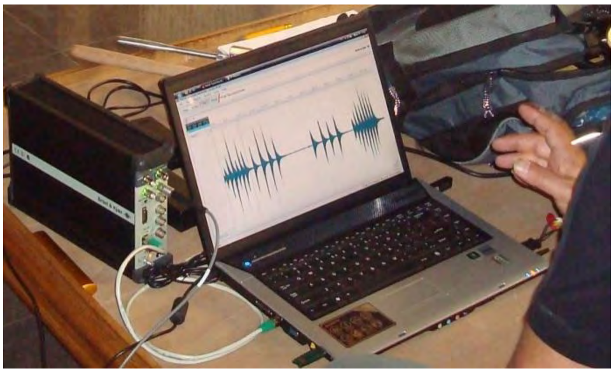


Fig. 4. Data Acquisition Unit 3560B Brüel & Kjær

Experimental set-up includes:

- Pressure-field Microphone Type 4193 Brüel&Kjær,[2] available in *Transducer Electronic Data Sheet* (*TEDS*) combinations with the classical Preamplifier Type 2669 with an individual calibration; Dynamic Range: 19 … 162 dB, Sensitivity: 12.5mV/Pa.
- Vibration Transducer TRV-01 SPM Instrument;
- Compact Data Acquisition Unit 3560B Brüel & Kjær, [2] for outdoor use that consist: Dyn-X input modules with a analysis range exceeding 160 dB and automatic detection of front-end hardware and transducers − supports IEEE 1451.4-capable transducers with TEDS (Transducer Electronic Data Sheet); output TCP/IP protocol communication - RJ 45 connector complying with IEEE−802.3100baseX; Multiframe Control option;
- Base software PULSE 12 for CPB (Constant Percentage Band) analysis 2 channels; 5-channel Time Capture; PULSE Bridge to MATLAB®
- MathWorks Software - MatLab&Simulink, toolboxes for FFT and Wavelet analysis.[3]

It can be seen, that the hardware equipment and the software manufacturers are known for theirs high quality all over the world. A part of equipments are shown in Fig.4.

C. Conformal map soundprint visualization

Wavelet analysis as a tool allows a deeper analysis of sound frequencies. The using of scalogram plots was providing new pictures for complex sounds structure.

In this section we analyze the Bell sounds structures. The preprocessed signals named “melnik1-1.mat” from **Melnik1** - 1270AD Bell and „melnik2.mat“ **Melnik2**-1220 AD are obtained by Brüel & Kjær’s Data Acquisition Unit 3560B,[6].

The Continuous Wavelet Transform signals calculations were produced in MatLab, Continuous Wavelet 1-D tool [3].

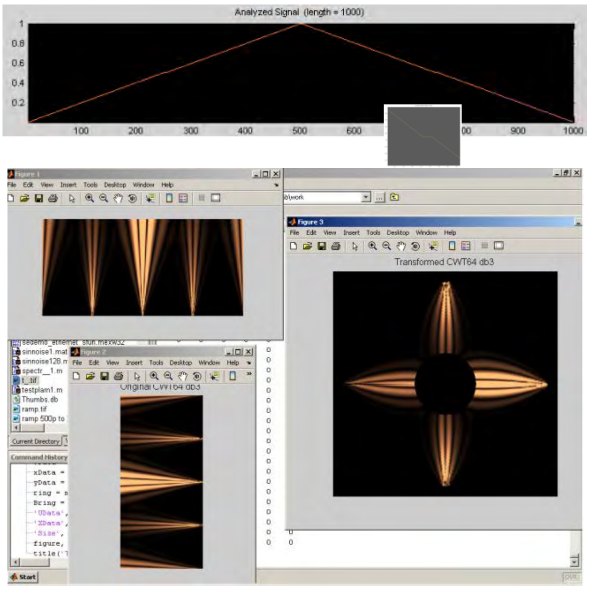
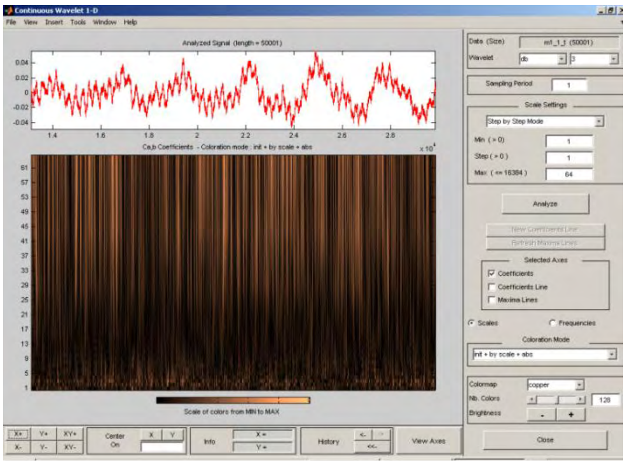


Fig. 5 An conformal mapping example, “NearBreaks I” test signal.

If we make known conformal mapping - logarithm function ln(z), the rectangular graph will be transformed to a circular graph. An example is given in Fig 5, where the signal is “Near Breaks I” test signal.

Fragments of bell strikes Melnik1 and Melnik2 in the time scale are shown in Fig.6 and Fig.8 respectively. The images that result from continuous wavelet transformations are illustrated to Fig.6 and Fig.8 in the bottom.

These scalogram coefficients are calculaated by Daubechies wavelets order 3.
On the figures 7 and 9 are illustrated the conformal map visualizations of the same bell strikes (Melnik1_10 and Melnik2_8) for various number of coefficients



Фиг. 6 Fragment of the signal Melnik1_10 - the strike tail, as well as its respective scalogram - CWT coefficients.

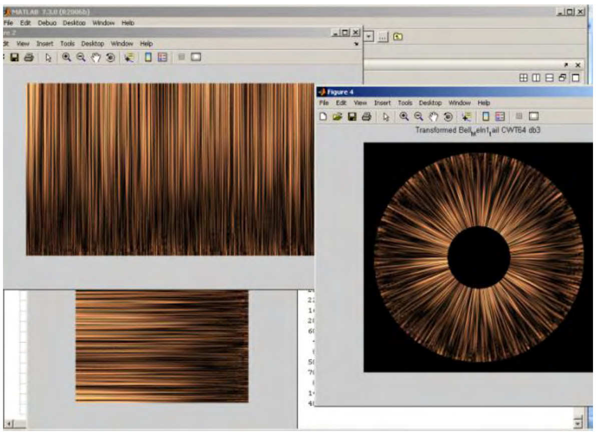


Fig.7 Conformal map visualization of the signal Melnik1_10

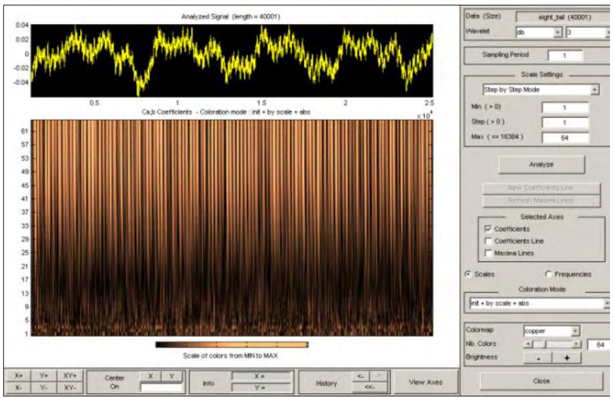


Fig. 8 Fragment of the eight strike tail and its respective scalogram (Melnik2_8) - CWT coefficient. Daubechies wavelets order 3.

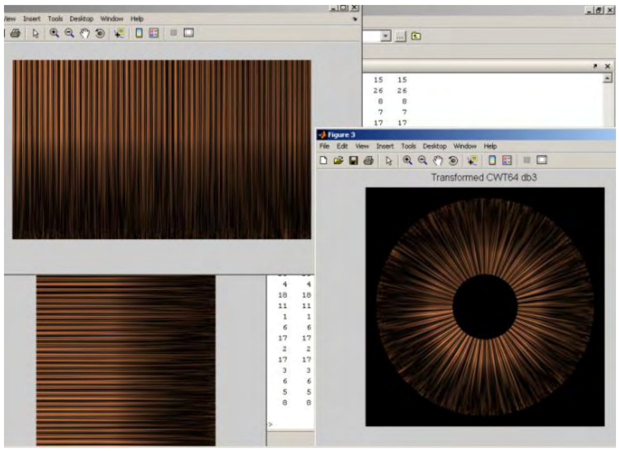


Fig. 9 Conformal map visualization of the signal Melnik2_8

In the figures 10 was shown fragments of the strikes (in tails) in left and in the right was shown theirs conformal maps.

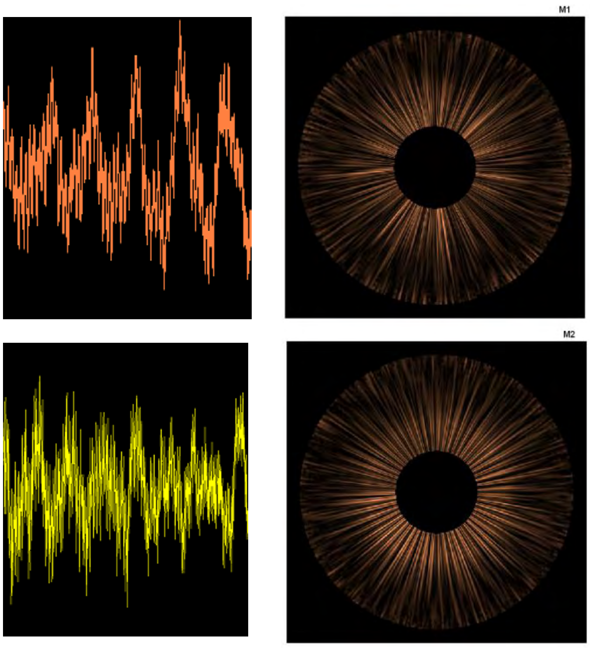


Fig. 10 *Visualization of the signals Melnik1_10(top) vs Melnik2_8*(bottom).

III. Additional Remarks

The possibility for analyze and perception is improved by transformation on two-dimensional acoustic signal image to pseudo three-dimensional (scalogram).

Additional improvement in perception is achieved by using a conformal mapping of the obtained scalogram, because there are well-known iris recognition techniques that can be applied.

IV. Conclusion

In the presented paper we propose a new method of presentation of some transformations (Fourier Transform and Wavelet Transform for example). Wavelet Transform, except its well known advantages, mentioned above, gives the improvement for analysis and reception via conversion of 2D signal into pseudo 3D signal (scalogram). Conform transformation improves these possibilities in addition. We introduce “sound print” as analog of the “fingerprint”, used in the criminology and biometrics. The detection and classification of the transmitted object becomes easily. This way the methods of biometric iris recognition can be used for process automation.

Our future work will be pointed to obtain more reasons of practical implementation of proposed method.

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Appendix

Bell’s donation inscriptions XIII century:

Bell Melnik2, 1211-1216 year
Material: bronze, Place: Tower-belfry on the metropolitan church of St. Nicholas, Melnik.

> *"† The bell /is/ forged out of copper, a gift from despot Alexii, † pious Slav to St. Nicholas, he who is from Mira.“*

Bell Melnik1, 1270
Material: bronze, Place: Belfry of the monastery of St. Charalambius - Saints Achangels, Melnik.

> *"Lord, help your servant Theodosii monk who for the first time has created (sanctified) a bell for strategus Mihail, the one that is in Melnik, this one that has been fixed under the reign of Michael Paleologus, the new Konstantine. In March, indiction 12 year 6778 (=1270)."*