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RESEARCH AND IDENTIFICATION OF VALUABLE BELLS OF THE NATIONAL HISTORIC AND CULTURAL HERITAGE OF BULGARIA*

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

Vivos voco.
Mortuos plango.
Fulgura frango

Abstract - *The aim of the "Research and Identification of Unique Bells as a part of the Historic and Cultural Heritage of Bulgaria and Development of Audio and Video Archive using Advanced Technologies*" project was to develop an archive containing detailed description of church bells.*

As an object of cultural heritage the bell has general properties such as geometric dimensions, weight, and localization. But its specific property is the sound. Thus, the archive contains also records of the sound of each of the bells, the pitch of the tone as well as acoustical diagrams obtained using contemporary equipment.

The audio and video archive is developed by using advanced technologies for mathematical modeling, spectral and wavelet analysis, reservation and data protection. The obtaining results can be implemented to the other type of vibrating objects. Some results are published on 'www.math.bas.bg/bells/'.

* This work was supported by the Bulgarian Ministry of Education and Science under Grant # KIN-1009, 2006

1. INTRODUCTION

The sound of the bells has been raising resonance vibrations, as in the physical environment, as well in the objects, so in the souls of the humans around them as well.

The bell's chime, as before several centuries so as well today showing one solid searching to euphony. The searching causes numerous changes in the casting technology, the construction (the profile), the weight and the number in a set, in the different stages to the history.

The bell's chime cannot be described with one note, even it is difficult to be described with assortment of notes as well. This is one complex sound that is percepted by human's hearing, that is different by the another percussion instruments ringing.

In that meaning measuring the large dynamic range sound is complicated task in entities as bell towers of churches and museum halls. The goal of the proposed work is to analyse the frequency components of the sound of the unique bell in the moment of the ringing as well as in the end of the transient process. [1,2,3,4,7,8]. In addition, the range of the parameters that characterize them can be estimated.[9]

2. HISTORY INFORMATION

The considered unique bells from XIII century are in the cardinal part of exhibition of hall "Second bulgarian empire", National Historic Museum (NHM), Sofia.

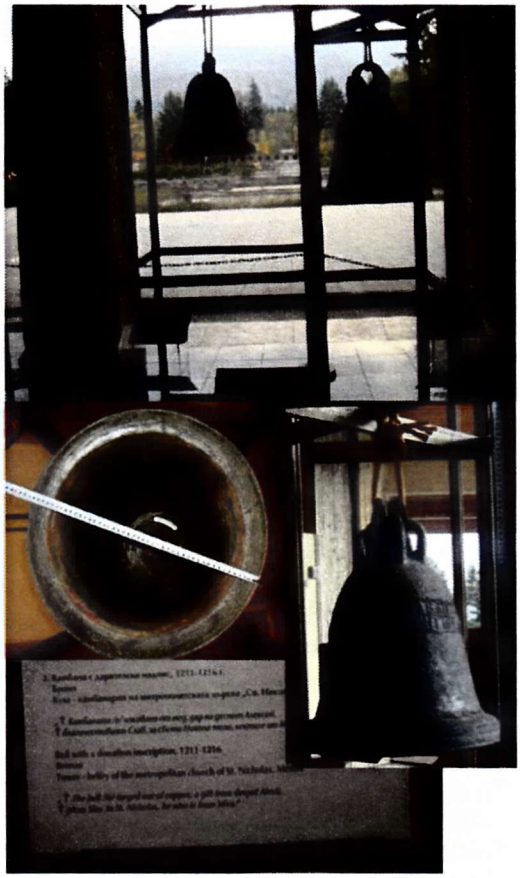

Fig. 1 *Special place in the exhibition has been dedicated to the bells.* "†The bell /is/ forged out of copper, a gift from despot Alexii, † pious Slav to St. Nicholas, he who is from Mira" *(Hall VII - XIV century, NHM, Sofia, Bulgaria.)*

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The **bell Melnik1** (1270yr.) is a gift from a nobleman from the entourage of the Byzantine emperor Michael VIII Palaiologos, called "New Konstantine" after the most respected from the church emperor Constantine the Great.

Bell **Melnik2** (1220yr.) is donation to the town from Despot Alexius Slav – a nephew of the The Asen dynasty in Second Bulgarian Empire, three brothers: Teodor I Peter IV, Ivan Asen I and Kaloyan. He was brother-in-law of Henry of Flanders the second emperor of the Latin Empire of Constantinople and he was establishing himself as an independent ruler over the most part of the Rhodope Mountains.

Bell's donation inscriptions are represented in **Appendix 1**.

In this work it will be consider an experimental set-up, realized to record the sound of unique bells, denoted as **Melnik2**-1220 yr. and **Melnik1** -1270 yr., shown in Fig.2.[2]

2. ACOUSTIC SIGNAL PROCESSING AND ANALYSIS

Fig.1 represents the bells in the museum hall of the National Historical Museum in Sofia. The disposition of measuring microphone 4193 Brüel&Kjær, [6] is illustrated in Fig.2.

Fig. 2 *Measuring microphone toward bell 'Melnik2' disposition.*

2.1 Experimental set-up

Experimental set-up includes:

- Pressure-field Microphone Type 4193 Brüel&Kjær,[6] 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, [6] 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.[10]

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.3.

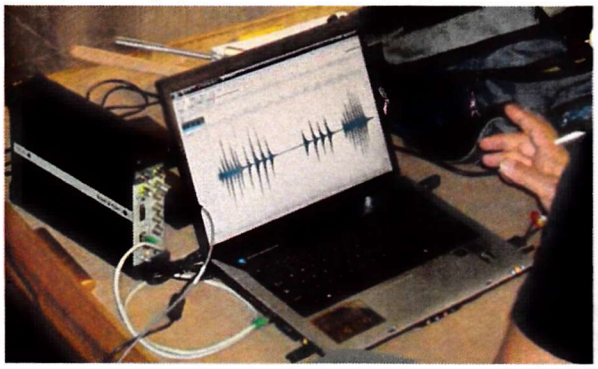


Fig. 3 *Data Acquisition Unit 3560B Brüel & KjærFont sizes for typewriting equation*

2.2 Frequency estimation of spectral components for bell chime by FFT

Some hits were produced by small wooden hammer. The record of the sound, produced by 12 hits of the hammer is shown in digital format in Fig.4 for Melnik2 bell.

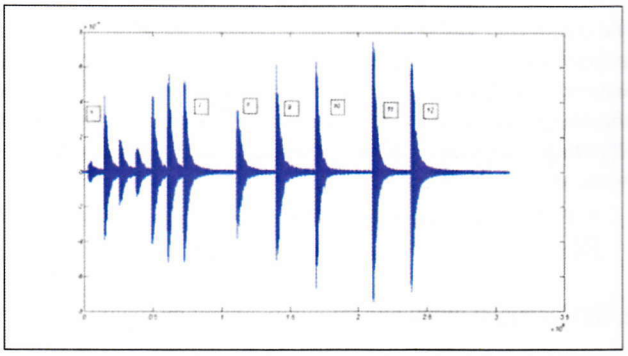
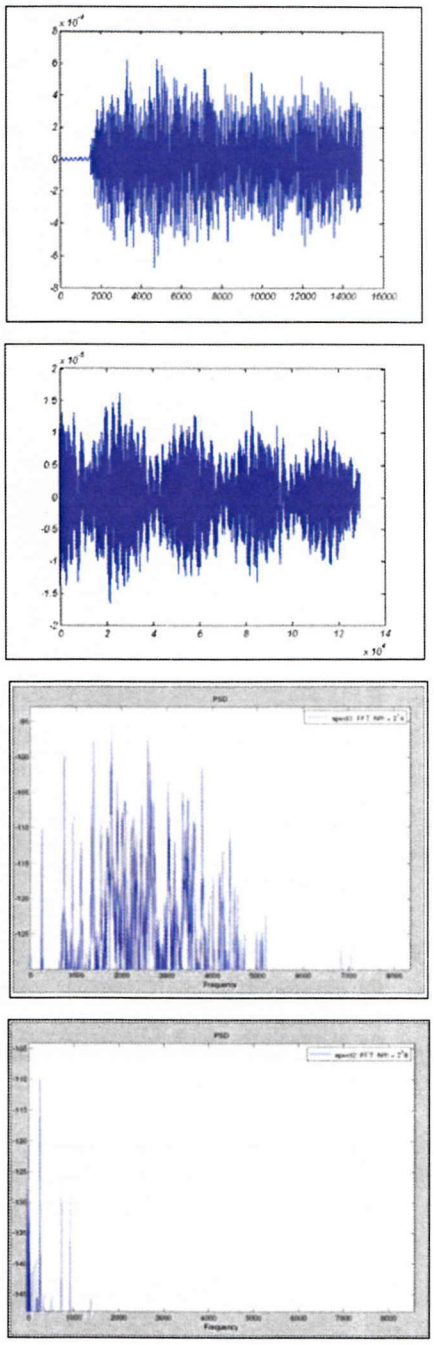


Fig. 4 *Signal "mel2.mat", 3109214 samples, sampling frequency Fs = 65536, distance to the microphone 5.2 meters (measuring microphone 4193 and Data Acquisition Unit 3560B Brüel & Kjær).*

This preprocessed signal "mel2.mat", after Data Acquisition Unit 3560B Brüel & Kjær, contains 3109214 samples, with sampling frequency Fs = 65536 samples per sec.

Fragments of tenth strike spreading in the time are shown and its spectral components are estimated in Fig.5.

The calculations was produced in MatLab, [10], where signal's power spectral density (PSD) was analyzed with the nonparametric method of Discrete Fourier Transform (DFT) – by Fast Fourier Transform algorithm (FFT).



5a)

5b)

5c)

5d)

Fig. 5 *Part of the front of signal "mel1.mat" (a) and fragment of the tenth strike tail (b), as well as its respective spectral densities (c) and (d).*

n the result, calculated estimations, made with the matched FT, show that power spectral density of one strike Melnik2) consists of principal spectral components, resented at Table 1:

The results, shown in Table1 was calculated analogically to he illustrated in paper [4] way, using the matched DFT only, 6].

Table 1 *Frequency estimation of spectral components for bell chime separated fragments (Melnik 1220yr. bell), nonparametric method with matched FFT. Results of experiment*

Strike number in the signal "mel2.mat "	Principal frequencie, Hz	Tail Principal frequencies, Hz	Notes
Eighth	284.125, 762.625; 1406.5; 1788.75	280; 760.	
Ninth	282.75; 762.5; 952.125;	281, 282.5; 763;	281 and 763 - max.
Tenth	282.75; 280.5; 760; 952.12.	24; 282.75; 280.5; 760.5.	24 (-121); 282.75 (-110) max; 760.5 (-127)
Eleventh	1407.5; 1788.8.	283.1; 761.5.	
Twelfth	284.125; 764.375; 952.37; 1406.375.	280; 760.	

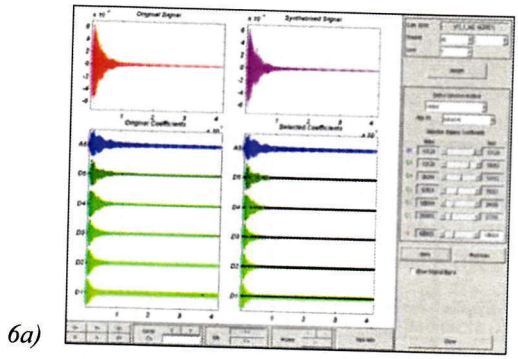
3. DAUBECHIES WAVELET APPROXIMATION OF PREPROCESSED SIGNALS

It was analyzed the approximation of the separate chime (tenth strike) of preprocessed signal "mel1.mat" – with the discrete wavelet coefficients selection Matlab's tool for one-dimensional signals – 'Wavelet Coefficients Selection 1-D'. It was selected the db3 wavelet - Daubechies Wavelet order 3 and 5 levels – db3.5. Wavelet coefficient selection strategy was 'Global selection of biggest coefficients (in absolute value)'.

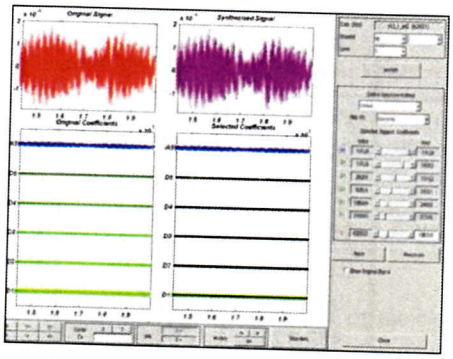
On the figures 6a), 6b) and 6c) are illustrated the approximation of the tenth strike for various number of coefficients s =106368 from total 420023 samples. Analogously for only 15780 from total 420023 samples at 8a), 8b) and 8c).

In the middle figures 6b), 8b) was shown fragment of the tenth strike tail and in the bottom two figures 6c) and 8c) was shown approximation residuals.

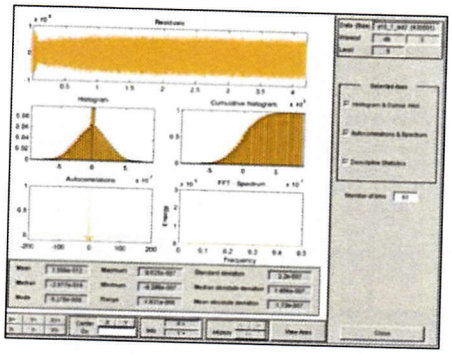
Fragments of the tenth strike tail after the reconstruction are illustrated at the figure 7 s =106368 and the figure 9 s =15780.



6a)



6b)



6c)

Fig. 6 *Approximation of the tenth strike for various number of coefficients s. For (a), (b) and (c) s =106368 from total 420023 samples*

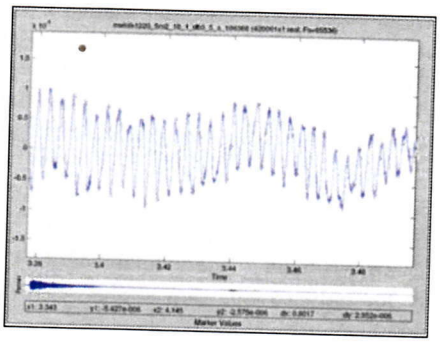
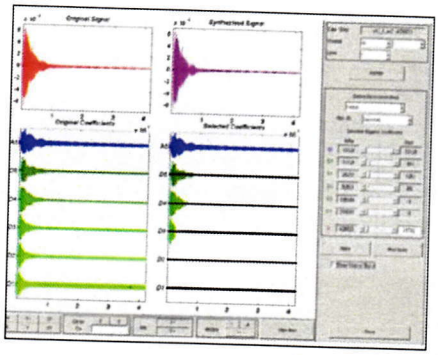
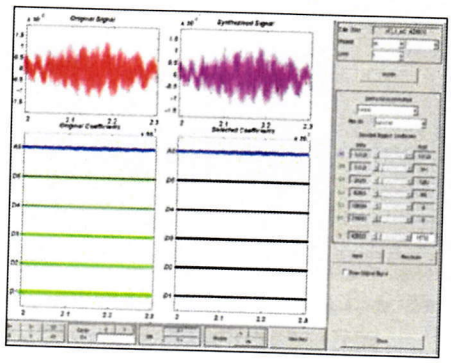


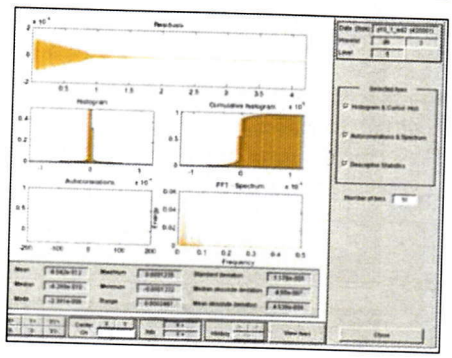
Fig. 7 *Fragment of the tenth strike tail after the reconstruction s =106368, from 420023 samples in all. Daubechies wavelets order 3 and 5 levels.*



8d)



8e)



8f)

Fig. 8 *Approximation of the tenth strike for various number of coefficients s. For (a), (b) and (c) s =15780 only from total 420023 samples at (a), (b) and (c).*

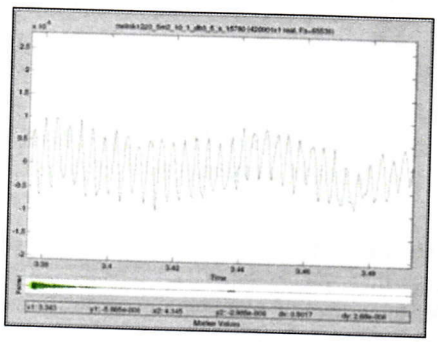


Fig. 9 *Fragment of the tenth strike tail after the reconstruction b) s =15780, from 420023 samples in all. Daubechies wavelets order 3 and 5 levels.*

4. DISCUSSION OF THE RESULTS

Conclusion

The obtained results are very interesting. Unique equipment and advanced methods of signal processing enable opportunity to find fine structure of chime components

Appendix 1

Bell's donation inscriptions XIII century:

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)."

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."

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