AN EXPERIMENTAL INVESTIGATION OF THE 122mm ARTILLERY SYSTEM FIRING ACOUSTIC FIELD

ЕКСПЕРИМЕНТАЛНО ИЗСЛЕДВАНЕ НА АКУСТИЧНОТО ПОЛЕ ПРИ СТРЕЛБА СЪС 122ММ АРТИЛЕРИЙСКА СИСТЕМА

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Abstract: *In the recent years, the battlefield acoustic exploration acquires a new dimension. This is due to the fact that modern weapons have a significantly increased distance of defeat, but the intelligence cannot detect such weapons at a sufficiently distance. In this connection the purpose of the present study is to investigate the near acoustic field of 122 mm artillery system firing. The collected with advanced technology equipment raw data were analyzed with the harmonic and wavelet analysis tools.*

Keywords: ACOUSTICS, ARTILLERY SYSTEMS, MICROPHONES, WAVELET ANALYSIS, SCALOGRAM

1. Introduction

Weapon acoustic analysis has practical applications in many fields such as security, gun control or military tactics. Thus, the acoustic signature produced by explosive propelled weapons has been subject of study from many years now [1]. In the recent years, especially in The Middle East and Afghanistan this field has become more relevant mainly due to the development of sniper detection, heavy weapons and localization systems. The biggest problem in this field is the strong dependence on the shooter's location and orientation shown by the recorded waveforms, mostly because the acoustic disturbance created by firearms is highly directional and its short time duration makes it behave like an impulse.

Our work describes analysis and results of measurements of the 122 mm 2S1 howitzer conducted at Markovo training range on the 05 of October 2017. The measurements were made at distance of 24 m from the muzzle of the weapon. This is one of the noisiest weapons in the Bulgarian army, and as such represents a limiting *factor* when planning firing ranges and training fields. The 2S1 was placed at Markovo training range just southeast of the City of Shumen, and there were two targets. The right one was at 1200 m from the howitzer, and the left one was at 1050 m, Fig.1.

Fig.1. *122 mm 2S1*

2. Preconditions and means for resolving the problem

2.1 Theoretical Model

2.1.1 Continuous wavelet transform method

Continuous wavelet transform (CWT) is used to analyze the structure of sound signals. The scalograms made up by this method ensures better visualization of the local characteristics of the signals.[2,5].

Like the Fourier transform, the continuous wavelet transform uses inner products to measure the similarity between a signal and an analyzing function. In the Fourier transform, the analyzing functions are complex exponentials, $e^{j\omega t}$. The resulting transform is a function of a single variable ω. In the CWT, the analyzing function is a wavelet, ψ. In contrast to traditional power spectral method, the continuous wavelet transform method is a joint time-frequency analysis method which can decompose a time series into time and frequency spaces simultaneously. The continuous wavelet transformcan be defined as:

$$W_x(\tau, a) = \int_{-\infty}^{\infty} x(t)\, \Psi_{a,\tau}^*(t)\, dt \qquad (1)$$

where W_x is the wavelet coefficient, $x(t)$ is the time series of experimental signal, $\Psi_{a,\tau}(t)$ is the wavelet function, and the symbol * denotes the complex conjugate. The wavelet function is obtained by varying the wavelet scale a and the time delay τ of the mother wavelet function $\Psi(t)$ as:

$$\Psi_{a,\tau}(t) = a^{-1/2}\psi\left(\frac{t-\tau}{a}\right) \qquad (2)$$

Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constituent wavelets of the original signal. There are many different admissible wavelets that can be used in the CWT. While it may seem confusing that there are so many choices for the analyzing wavelet, it is actually strength of wavelet analysis. [2]

2.2 Experimental setup

The experimental layout is pictured in Fig. 2.

Fig.2 *A part of hardware for data acquisition of pulse acoustic signals*

The hardware and accessories are listed in Table 1.

***Table 1**: Hardware and accessories.*

Laptop Lenovo Think Pad E540
Laptop Toshiba Satellite C650D-112
1/2" Pressure-field Microphone 4193, Brüel & Kjær
Data Acquisition Unit 3560-B-110, Brüel & Kjær

The records were made using microphone Brüel & Kjær Type 4193, with the following features:

- Sensitivity: 12.5 mV/Pa
- Frequency: 0.07 Hz-20 kHz
- Dynamic Range: 19- 62 dB
- Temperature:-30 to +300°C (-22 to +572°F)
- Polarization: 200 V [3]

and processed by the Multi-Analyzer System Type PULSE 3560-B-110, Brüel & Kjær with features:

- Frequency Range - from 0 Hz to25.6 kHz;
- Aux. Channels - 16 Aux Input, (10 samples/s, 2 Digital Output;
- Simultaneous Channels - 5 Input, 1 Sine Output;
- Connectors – LEMO, BNC;
- Input Type – LEMO - Direct/CCLD /Mic. Preamp1 Tacho Conditioning
- BNC - Direct/CCLD/1 Tacho Conditioning. [4]

The microphone was placed 4,5 m above the ground, 24 m. away from the muzzle of the howitzer and at an angle of approximately 120 degrees from the muzzle direction. Single shots and salvo were recorded during the firing exercises.

2.2.2 Acoustic source

The acoustic pressure field was generated by a self-propelled field Howitzer – 2S1 "Gvozdika". This has a 122 mm barrel with a maximum chamber pressure approximately 40MPa. The ammunition modules were 3VOF5, each containing 3.67 kg propelling charge. The data were collected from four blasts.

2.2.1 Meteorological conditions

The weather was still with no cloud cover, and stable over the entire measurement period. No temperature or pressure profiles were recorded. The conditions are summarized in Table 2.

***Table 2**: Meteorological overview*

Quantity	Value
Temperature	22°C
Atmospheric pressure	1027 hPa
Humidity	40%
Wind speed	2 m/s

2.2.2 Measurement and results

Explosive propelled weapons produce their characteristic sound as a result of the rapid expansion of gases at the end of their barrel, formally known as muzzle blast. The second component is the shock wave created by supersonic projectiles. It is commonly called N-wave due to its characteristic geometry and, unlike the muzzle blast, it has a local influence since it only appears at distances close enough to the trajectory of the projectile. In close range recordings, ground reflections from both muzzle blasts and shock waves, along with the sound produced by the firing mechanism of the weapon, are most likely overlapped with the direct signal. Fig. 3 illustrates recorded muzzle blasts from two 2S1 howitzer firing simultaneously.

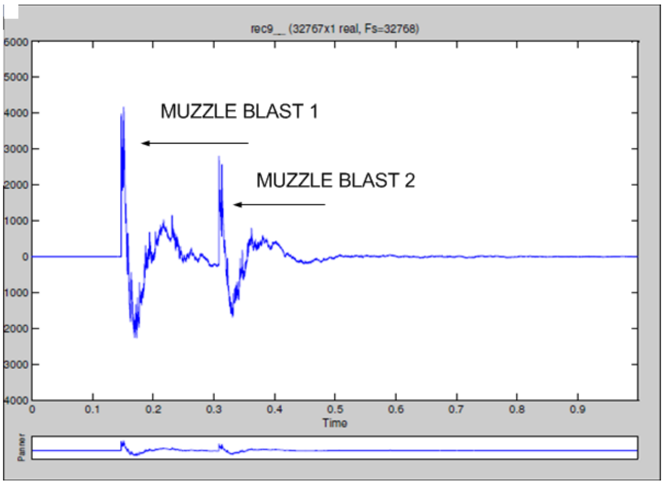
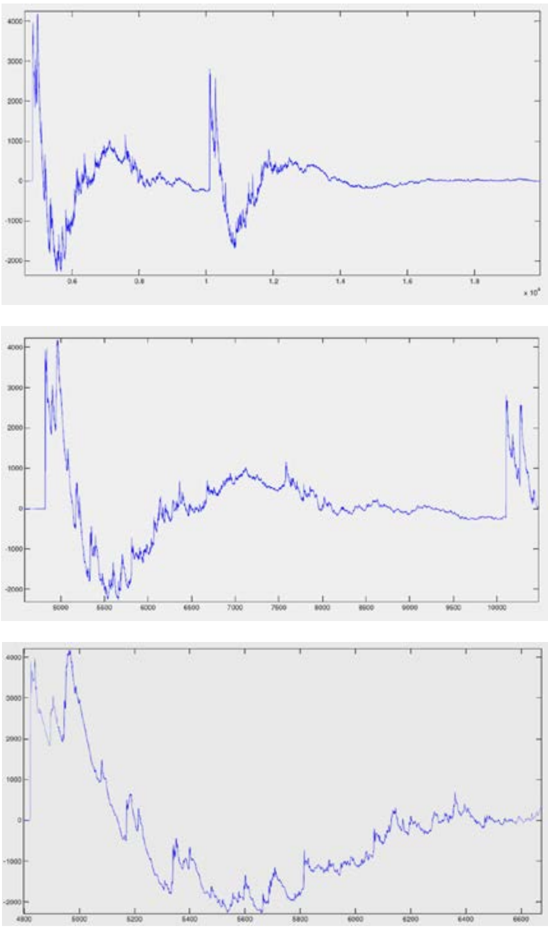


***Fig. 3** Recorded muzzle blasts.*

The data from the training range, collected during the tactical exercises, on the 05 of October 2017, were exported from PULSE platform as *mat* files and *wav* files, to be processed in MATLAB®. The signals, captured from the microphone, were analyzed in time-frequency domain and time-scale domain.

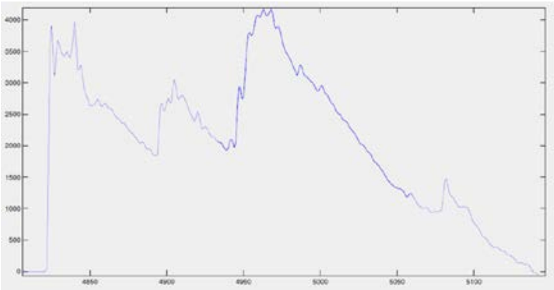
A four parts time signal from the first blast from 122 mm 2S1 howitzer ("Gvozdika ") is illustrated on Fig.4, where a) is the signals captured from two blasts from the two howitzers ("Salvo"), b) is the first from two blasts , c) is the first 1800 samples and d) first 300 samples, $Fs = 2^{16} samp./sec.$



a)

b)

c)



d)

Fig. 4 *Some pulse acoustic signals. a) the signals captured from two blasts ("Salvo"), b) the first from two blasts , c) the first 1800 samples and d) the first 300 samples,* $\boldsymbol{Fs = 2^{16}}$ *samp./sec.*

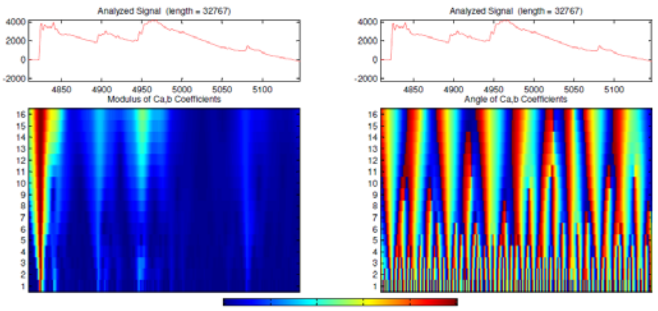


Fig. 5 *Contour plot of the Gauss wavelet coefficients, complex wavelet cgau3, a=16, sampling period 2to16*

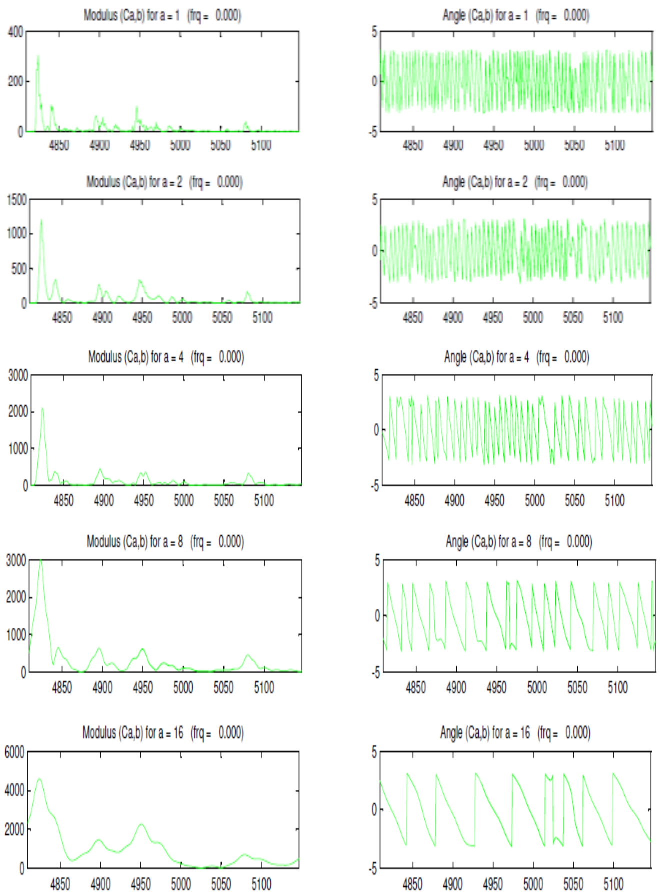


Fig. 6 *Coefficients lines for complex wavelet cgau3, a =1, 2, 4, 8 and 16.*

It is known that the complex Gaussian function family is built starting from $C_p e^{-ix} e^{-x^2}$, [6]. C_p is such that the 2-norm of the p^{th} derivative of Ψ is equal to 1, $\left\|f^{(p)}\right\|^2 = 1$.

A complex wavelet function such as Gaussian complex wavelet return both amplitude and phase information. When this wavelets for the time signal is applied, the result is shown in Fig.5, and it contains useful acoustic information.

The coefficients lines for some scale parameter values, a =1, 2, 4, 8 and 16, are displayed in fig. 6 and the maxima lines for a =1, 2, 4, 8 and 15, are displayed in fig. 7.

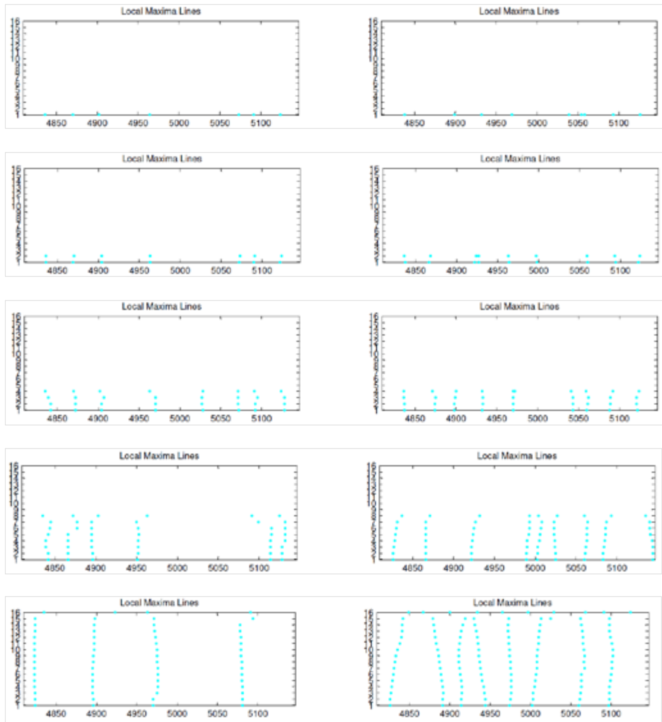


Fig. 7 *Maxima lines for complex wavelet cgau3, a =1, 2, 4, 8 and 15 (in the top, a=1, the bottom a=15, in left modulus in right angle)*

3. Conclusion

The complex wavelet function transforms and its application in shooting analysis are discussed in this paper. The complex Gaussian wavelet transform was used for analyzing the time captured signals. It was demonstrated that this transform was appropriate to detail analysis the characteristics of blast acoustic signals.

4. Acknowledgments

This work was supported by Operational Program Science and Education for Smart Growth 2014-2020, project BG05M2OP001-2.009-0001, co financed by the European Union under the European Social Fund.

5. References

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