WAVELET ANALYSIS OF ACOUSTIC SIGNALS

УЕЙВЛЕТ АНАЛИЗ НА АКУСТИЧНИ СИГНАЛИ

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Abstract: *In modern warfare there has been increased use of various weapon systems like tanks, artillery, mortars, infantry armored vehicles, multiple launch rocket system (MLRS). Hostilities often are conducted in densely populated urban areas, where most victims are given by the civilian population. It is the application of systems of detection and reconnaissance sources of sound (the weapons), and also the quick disclosure of their locations. It achieves a "rapid response" of the threats and reduces casualties. Wavelet analysis offers a quick way to process acoustic signals received in the shooting which provides the opportunity for quick reconnaissance and defining sources of sound.*

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

1. Introduction

Wavelet and wavelet transforms have become popular tools of signal processing and mathematical modeling because of the various advantages they have over traditional techniques. The Fourier Transform decomposes a signal into a frequency spectrum at the loss of time domain information. Wavelet transforms involve decomposing a signal into various levels to study frequency patterns over time. High frequency characteristics in the lower levels and low frequency characteristics in the higher levels allow the analyst to make predictions regarding the nature of the signal. [1]

Weapon acoustic analysis has practical applications in many fields such as security, gun control or military tactics. In the recent years, this field has become more relevant mainly due to the development of sniper detection, heavy weapons and localization systems. The biggest problem 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.[2]
This paper describes analysis and results of measurements of the 152 mm towed D-20 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 the noisiest weapon in the Bulgarian army, and as such represents a limiting *factor* when planning firing ranges and training fields. The D-20 was placed at Markovo training range southeast of the City of Shumen. The right target was at 1900 m from the howitzer, and the left one was at 2000 m. Targets were shown on Fig.1.The D-20 howitzer is shown on Fig.2

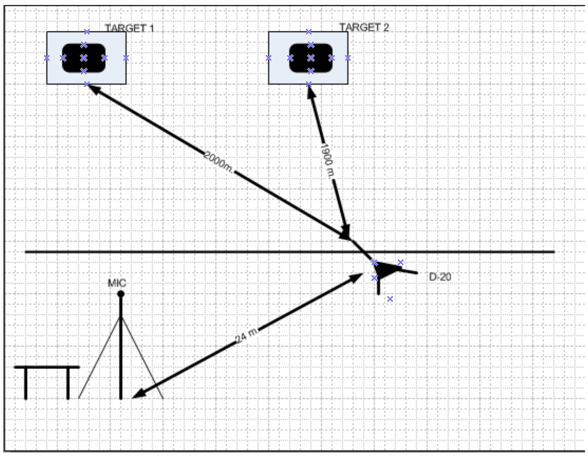

Fig.1.*Targets*

Fig.2

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.[3,6].
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]

2.1.2 Gunshot Acoustic Model

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 energy of the explosion, thus, the radius of the gas sphere (Weber radius), is directly related to the wavelength of the blast. The second component is the shock wave created by supersonic projectiles. For a projectile with a speed $V > c$, definingMach number as $Ma = V/c$, where c is the speed of sound, the generated shock wave propagates in conic shape forming an angle θ $Ma = arcsin(1/Ma)$ with the bullet trajectory as shown on Fig. 3.[2]

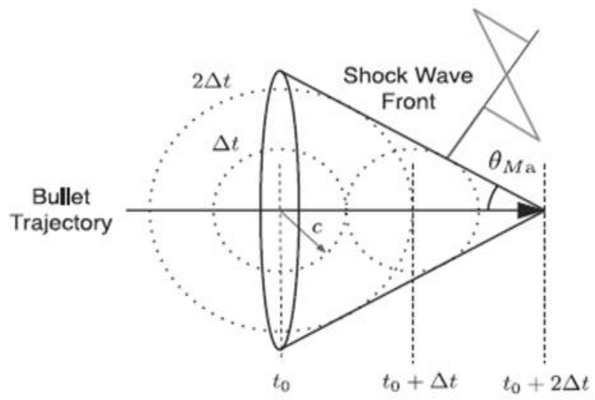

Fig.3 *Bullet Trajectory*

2.2 Experimental setup

The experimental layout is pictured in Fig. 4.

Fig.4 *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 45 degrees from the muzzle direction. Only single shots were recorded during the firing exercises.

2.2.1 Acoustic source

The acoustic pressure field was generated by a 152 mm gun-howitzer M1955 also known as the D-20. Its GRAU (Main Missile and Artillery Directorate of the Ministry of Defense of the Russian Federation) index is 52-P-546. D-20 has has a 34 calibre (5.195 m) barrel, with a double baffle muzzle brake and a semi-automatic vertical sliding block breech, with a tied jaw and the block moving down to open. The barrel is mounted in a long ring cradle with the trunnions just forward of the breech.

Specifications:

- Weight 5,700 kg;
- Length 8.69 m;
- Barrel length 5.195 m;
- Width 2.35 m;
- Height 1.93 m;
- Shell Separate loading charge and projectile;
- Caliber 152.4 mm;
- Muzzle velocity 650 m/s;
- Effective firing range 17.4 km;
- Maximum firing range 24 km. [8]

2.2.2 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

2.2.4 Measurement and results

Measurements were made simultaneously by PULSE system with ruggedised laptop – TOSHIBA SATELITE C650D-112 and COTS (Commercial off-the-shelf) – Lenovo Think Pad E540. In our work we use only results measured by PULSE System. 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. 5 illustrates recorded muzzle blast from D-20 howitzer.

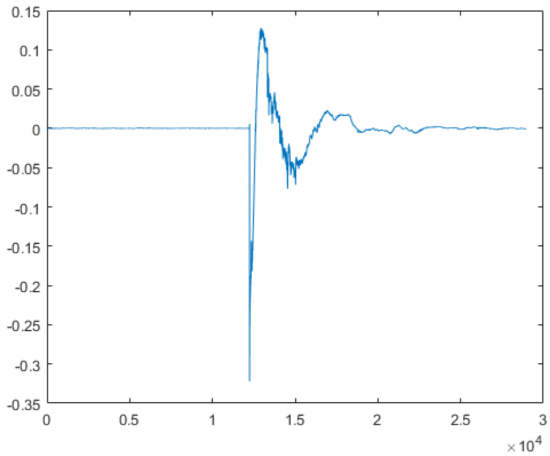

Fig. 5 *Recorded muzzle blast.*

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 signal from the blast from 152 mm towed howitzer D-20 is illustrated on Fig.6.

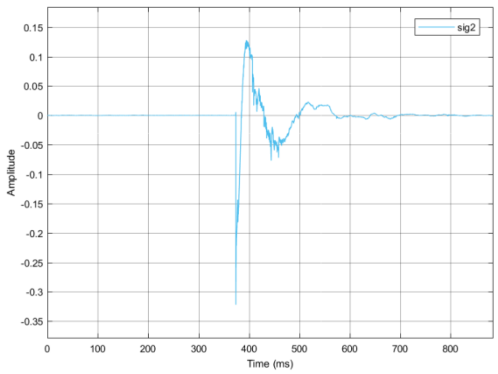

Fig. 6 *Pulse acoustic signals. 28942samples,* $\boldsymbol{Fs = 32768Hz}$

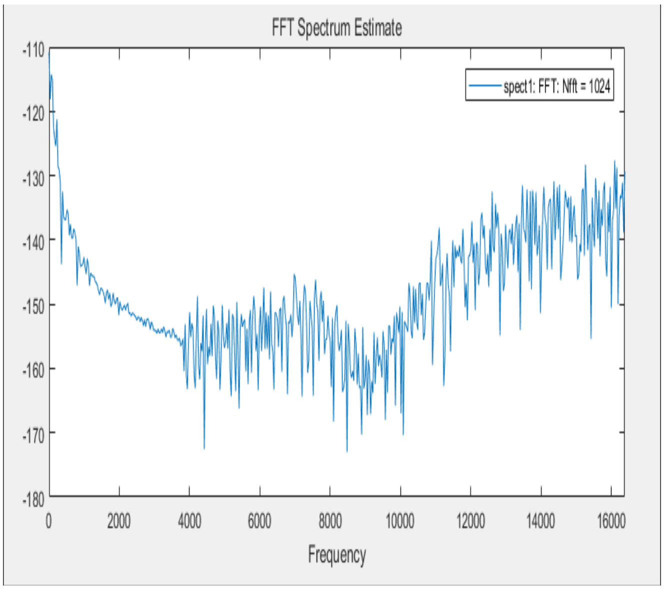

Fig. 7 *Spectral density of the recorded signal 28942samples,* $Fs = 32768Hz$

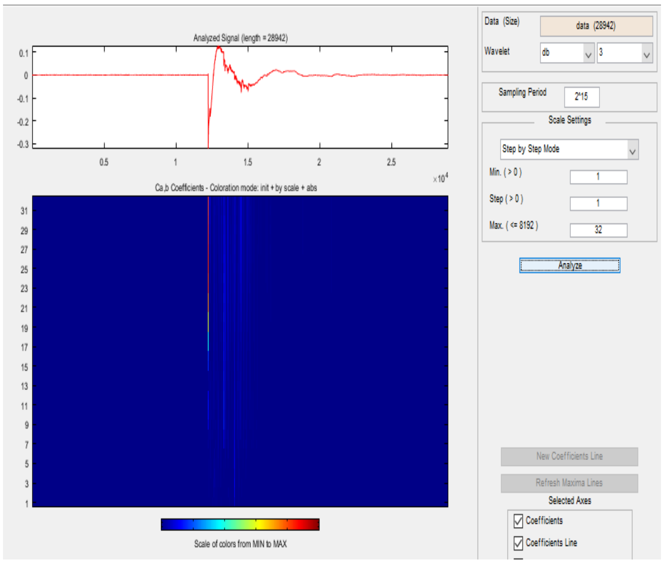

Fig.8 Continuous 1-D wavelet transform, 32 scales, jet color pallette

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, $\|f^{(p)}\|^2 = 1$.

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.8, and it contains useful acoustic information.

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

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