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A Digitally Manipulated Gunshot Sound Identification

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Abstract. **It is actual problem to distinguish between real gunshot sound pictures from tactical weapons and from fabricated or manipulated ones.**
In this work, some possible approaches to digital manipulation detection in gunshot records are described. The study uses methods of temporal and spectral analysis, revealing fine changes in signals, in a comprehensive dataset that consist of the raw data of gunshot sounds.
The purpose of the work is to consider some approaches to digital manipulation detection in gunshot records
High accuracy in the identification of manipulated sounds is demonstrated, with a low percentage of false positives and a high percentage of true positives.
This research lays the groundwork for a comprehensive database of gunshot signals. This database has potential value for further analysis using methods like the Continuous Wavelet Transform.

Keywords: gunshot analysis, digital manipulation detection, audio authentication.

I. INTRODUCTION

Recently, various methods of identifying tactical firearms, based on gunfire audio signals data, have been demonstrated. In general, they used Deep learning methods, as can be seen in the works [1], [2]. They demonstrate the powerful capability to extract essential features of datasets from some sample sets. So, the deep learning sound recognition has gradually become the mainstream research direction.

The methods for gunshot recognition proposed by researchers at present have their own advantages and disadvantages. If it is needed to work in real-time the difficulties are connected with the large amount of model calculation and high hardware requirements.

Sometimes recordings are captured on a phone microphone and they have a low fidelity, non-professionally recorded audio.

It is known that in case of recording of guns and explosions, that their accurate representation on a recorded medium is a complicated problem because they are too loud to reproduce in with any authenticity. The real gunshots are not so attractive as the movies unless one is very close to them.

The aim of the work is to consider some approaches to digital manipulation detection in gunshot records.

The collection of raw acoustic data, as well as their processing in field conditions, is invariably accompanied by certain difficulties. So, during tactical training on a training range, the registration and primary processing of signals is under the influence of noises which have a different character. Numerous approaches are known for their reduction of the noises, some of which can be seen in [3], [4].

On the other hand, additional techniques can be used in post-processing. When extracting knowledge from data - data mining, it is important to study the properties and character of random processes, realizations of various noises. In the work [5] application of wavelet packet entropy to such algorithms is considered. Some current algorithms for statistical analyzes are presented in Angelova-Slavova's work [6]. An approach to the study of acoustic noises by means of wavelet transformations is shown in the works [7] and [8]. Also, statistical processing using computer software is presented in [9].

Some problems for detecting the manipulation of sound signal recording are that they face the following challenges [10]

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- Compression: Lossy audio compressions typically contain some form of non linear quantization together with selective frequency reduction.
- Channel effects: Transmitting compressed audio through a channel might induce transmission related data loss such as packet loss, noise and more. Channels for example can be VoIP, landline, cellular or satellite.
- Bandwidth differences and filtering: Audio codecs can differ by bandwidth, as some codecs are narrow band and others are wide band.
- Unseen spoof attacks: One of the main challenges of an anti spoofing system is to generalize and to detect unseen attacks from an unknown distribution.

II. SOUND DATA SET COLLECTION

When working in field conditions (besides the standard temperature, pressure, humidity), the following environmental conditions are significant: the presence of an open space or forest; signal strength or noise; the distance between the source and the recording device; wind strength and direction; the direction of the sound relative to the recording devices.

Here are regarded some examples from sound data sets.

A. Hail dropping strikes

For example, the noise spectral characteristics of hail dropping strikes in urban environment have been analysed in [11]. In this study, the spectra of two hail storm recordings were compared. One recording (see Fig. 1) was made with professional hardware (Brüel & Kjær 3560-B-110 and measurement microphone 4193), while the other was extracted from a video clip on the "Severe Weather Europe" website.) Analysis revealed strong low-frequency spectral components in the recording made with professional hardware. However, these low-frequency components were absent in the recording sources from the online report.

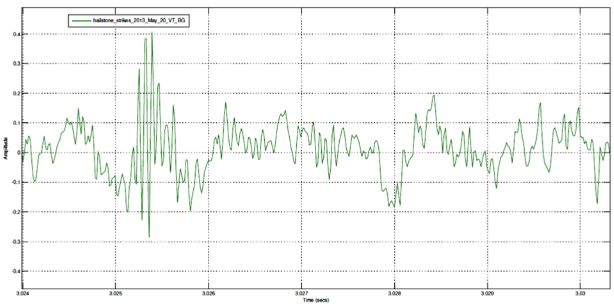


Fig. 1. Part of hail dropping strikes noise (in urban environment), 6ms duration, sample frequency 2to16 samples. See [11].

Figure 2 illustrates the estimated power spectrum density components for a sample of hail dropping strike noise.

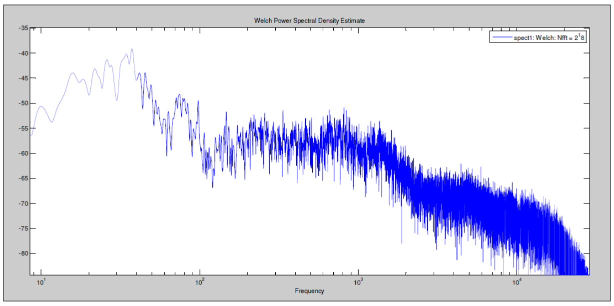


Fig. 2. The smoother spectral components, in dB, bandwidth 10 Hz – 20kHz for noise of hail STFT, Hanning window, overlap 0.5, Welch method, sample freq. 65536Hz. 20 May 2013,V. Tarnovo, BG.

Figure 2 shows the signal's power spectral density (PSD) calculated using the Welch method with a Hanning window. The analysis focused on the 10 Hz – 20 kHz bandwidth, which is relevant to the noise of hail (sample frequency 2-16 Hz). Strong spectral components are visible within the 20 Hz to 40 Hz range.

B. Sound of thunder

This section examines the noise spectral characteristics of thunder, drawing upon studies [13, 14]. A thunder noise recording was made in June 2012 using professional-grade equipment (Brüel & Kjær 3560-B-110 and measurement microphone 4193). This recording provides a high-quality sample for analysis.

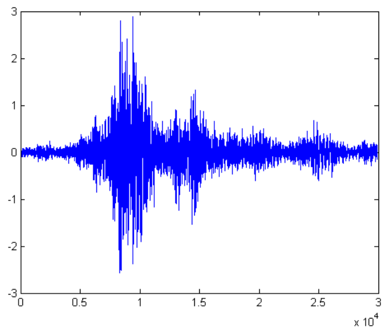


Fig. 3. Record of a thunder noise, Brüel&Kjær 3560-B-110 and the measurement microphone 4193 June 2012,V. Tarnovo, BG., [14]

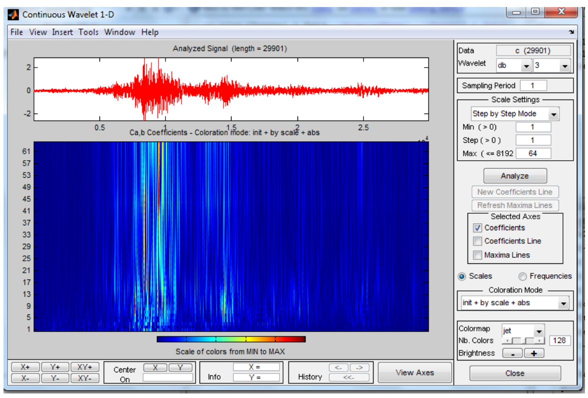


Fig. 4. Scalogram, Continuous Wavelet Transform of thunder record, [14].

It is known that thunders produce very large dynamic pulses with a frequency range extending beyond audible sounds, including infrasound waves (frequencies below 20 Hz).

C. Manlicher carbines firing sound

The next sounds that are considered are the pulse noises from firing with carbine in field demonstrations.

The experimental work was held at the Belyakovets training area, near V. Tarnovo during the tactical exercises on the 29th Apr. 2021,. Weather conditions was favourable: air temperature 11.6°C-13.4°C, wind speed 0.4 m/s, atm. pressure 1016 hPa, air humidity: 67-77%.

Specifically, the signals were from firing of Manlicher carbines, which were in service with the Bulgarian Army during the wars of the early 20th century, [12].

The sound sources are on level ground, with a concrete building nearby that also introduces acoustic reflections.

The experimental set-up is on a wooden tower, located in the grassy part of the range, at a height of three meters above the surface.

The setup includes precision instrumentation: the Brüel & Kjær Data Acquisition Unit 3560-B-110 and 1/2" Pressure-field microphone 4193.

Impulse signals and noise was seen in the field on a real time scale using constant percentage bandwidth - CPB or 1/3-octave analysis with the PULSE Labshop module 7771, see Fig 5,6.

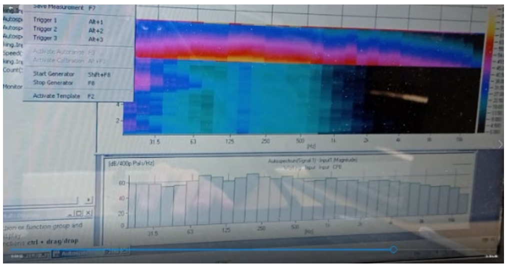


Fig. 5. CPB - real-time analysis, fragment 1, [12].

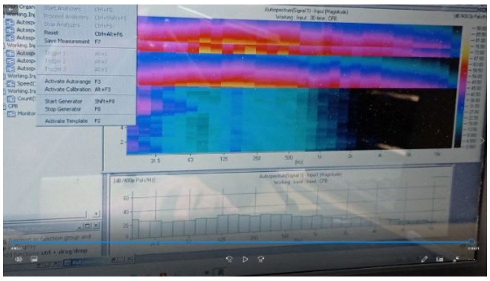


Fig. 6. CPB - real-time analysis, fragment2, [12].

III. Sound Signal Recording and Authenticity

The work of Raponi et al. [1] explores audio-based firearm identification. They created a dataset of 59 firearm types from YouTube videos and developed a convolutional neural network (CNN) for firearm classification. Their CNN achieved over 90% accuracy in identifying the category, caliber, and model of firearms from audio recordings.

It is interesting that they introduced a novel technique that requires zero knowledge about the recording setup and it is completely agnostic to the relative positions of both the microphone and shooter.

In Jian Li et all paper [2], is proposed an efficient method of gunshot recognition, which uses multi-layer neural networks to extract the representation features in the log-mel gunshot spectrogram, see Fig.7, so as to fully tap the relevant information between gunshot spectrum.

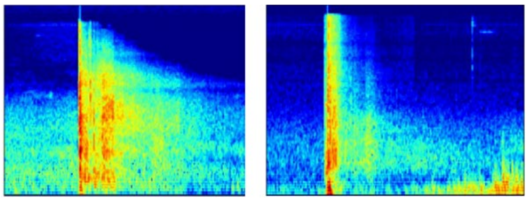


Fig. 7. Spectrograms of AK-47 gun sound in left YouTube gunshots dataset; in right NIJ Grant gunshots dataset, [2].

These solutions will improve the gunshot recognition method, initialize the weight of the network model by means of large dataset pre-training.

Many raw recordings of a variety of natural noises as well as impulse noises from tactical fire systems in field tests were collected [14],[15].

Reference [13] discusses signal processing methods like Continuous Wavelet Transform (CWT) and conformal maps for identifying non-stationary acoustic signals with a large dynamic range and wide frequency bandwidth. The study found that the conformal representation of the scalogram improves the visualization of these signal's special features.

As can be seen, Fig.8 CWT and conformal maps, gives some advantages for signal irregularity detection.

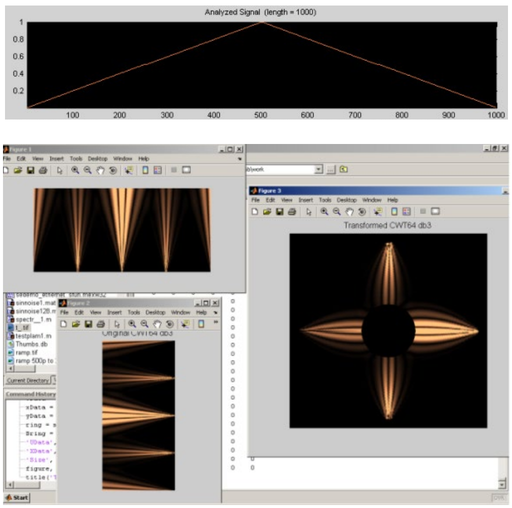


Fig. 8. Conformal map of Continuous Wavelet Transform for triangle pulse with breaks, [13].

Wavelet transform work as mathematical microscop and can help to make detail analysis of analysis of sounds discontinuity.

Next pictures show te examination of a pistol shot, Fig. 9,10.

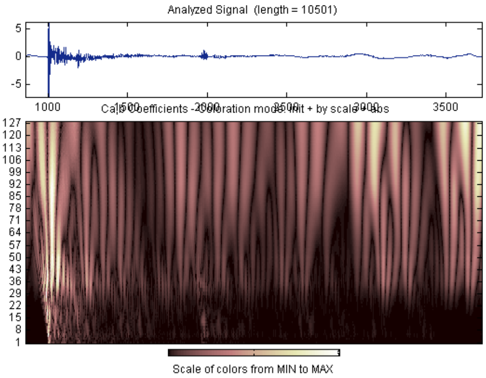


Fig. 9. Scalogram of the pistol shot, [13]

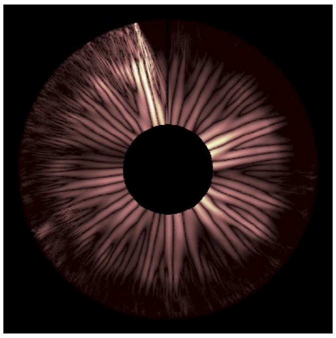


Fig. 10. Sound print of the pistol shot, [13]

Many signals obtained from the field recordings were exported in 32-bit wave format to MATLAB, where spectral analysis and CWT was performed. One example of guns scalograms are shown at Fig. 11, see [15].

This project collected a variety of raw recordings, including natural noises and impulse noises from field tests of tactical fire systems. The use of scalograms for building deep learning datasets is proposed.

IV. Conclusions

The digital manipulation detection techniques discussed in this study have direct applications in the analysis of raw acoustic pulse noises from gunshots. In addition, our collected from tactical field tests impulse noises may use as large dataset for initialization of network model weights and conformal representations of their scalogram may improve their visualization.

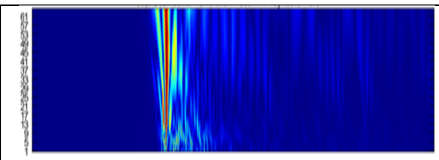
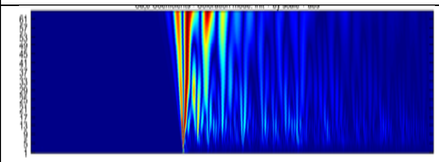
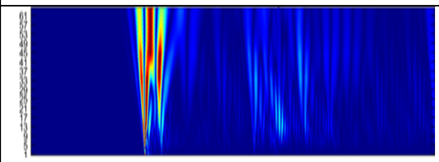
AK-47	
Armored battle machine – BMP-23	
73 mm anti-tank rocket launcher	

Fig. 11. Scalograms of CWT, [15]

Finally, this research lays the groundwork for a comprehensive database of gunshot signals. This database has potential value for further analysis using methods like the Continuous Wavelet Transform (CWT).

V. Acknowledgments

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