Research on the Energy Characteristics of Battlefield Blasting Noise Based on Wavelet Packet

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Abstract. When the acoustic fuse of smart landmines tries to detect and recognize a ground vehicle target, it is usually affected by gun shooting, explosive blasting or other similar noises on the actual battlefield. To improve the target recognition of smart landmines, it would be necessary to study the characteristics of these acoustic signals. Using sample data of the shooting noise of a certain type of rifle, the blasting noise of TNT, and the acoustic signals of a certain type of WAV, the energy characteristics of these noise signals are compared and analyzed. The result shows that the wavelet-packet energy method is effective in describing the characteristics of these acoustic signals with distinct intertype variations, and the frequency at the peak energy value can serve as a signature parameter for recognizing battlefield blasting noise signals from vehicle target signals.

1. Introduction

Smart landmines are known to be affected by wind, rain and other natural noises when trying to detect near-surface passive acoustic signals from as tanks, wheeled vehicles and helicopters. On real battlefields, to add the complexity, gun machine shooting, and explosive blasting are also great obstacles that can heavily prevent smart landmines from recognizing and locating target sounds. To solve this problem, it is necessary to study these battlefields blasting noise signals and analyze their time frequency so as to provide analysis data for the target recognition algorithms for the acoustic fuses of smart landmines, and improve the recognition rate of near-surface targets.

As acoustic signals have been proved to be a non-stationary process [1], it is somewhat deficient to approximate these signals to stationary ones when analyzing them by following the conventional time-frequency methods like Short-Time Fourier Transform (STFT) and Gabor Transform [2][3]. As animals are incomparable in recognizing sounds, some researchers tried to use the biomimic analog auditory system for recognizing acoustic targets [4]. Linear predict code cepstral coefficient (LPCC), Mel frequency cepstrum coefficient (MFCC), perceptual linear predictive coefficient (PLPC), harmonic set, and wavelet (packet) energy are the most frequently used signature parameters for analyzing acoustic signals [5][6].

In this paper, the acoustic signals of two typical battlefield blasting noises, rifle rooting and TNT blasting, are examined, their wavelet-packet energy features are extracted, and compared with the energy features of the acoustic signals of a type of WAV when in motion. The result shows that the
wavelet-packet energy method can well describe the energy features of blasting noise signals, and is effective in extracting useful information from acoustic signals, thereby allowing accurate recognition of the acoustic signals of vehicle targets from blasting noises.

2. Experiment
The acoustic signals from the shooting of a type of rifle and the blasting of TNT were compared with those acquired from a type of 8x8 WAV when in motion.

The signal acquisition system was composed of a B&K4189 acoustic sensor, a B&K2690 amplifier, and an Adlink USB-2405 high-accuracy data acquisition instrument. Sampling was conducted at the frequency of 2048Hz and amplification factor of 3.16v/pa. Figure 1 and Figure 2 show the composition of the acquisition system and the layout of the measuring system.

**Figure 1.** The composition of acoustic signal acquisition system.

The measuring site was 250m from both the rifle shooting and explosive blasting sources; the runway of the WAV is 200m long; the measuring site was on the edge of the measuring site with a vertical distance of 6m from the centerline of the runway; the WAV moved at 30km/h, as shown in Figure 3.

**Figure 2.** Measuring point location.
Figure 3. Measuring site location.

3. Wavelet-packet energy analysis

3.1. Principle

The acoustic signals of both the target and the blasting are non-stationary random signals. Wavelet-packet analysis, a decomposition method more precise than wavelet analysis, provides a higher time-frequency resolution as it decomposes both the low and high-frequency parts of each level. The wavelet-packet decomposition algorithm is as follows:

\[ d_j^{j,2n} = \frac{1}{\sqrt{2}} \sum_k h_{0(k-2l)} d_{k}^{j+1,n} \]  

(1)

\[ d_j^{j,2n+1} = \frac{1}{\sqrt{2}} \sum_k h_{1(k-2l)} d_{k}^{j+1,n} \]  

(2)

where: \( \{d_k^{j+1,n}\} \) is the wavelet-packet decomposition result of the previous level; \( \{d_j^{j,2n}\} \) and \( \{d_j^{j,2n+1}\} \) are the decomposition results of the next stage; \( j \) is the scale index; \( l \) is the location index; \( n \) is the frequency index; \( k \) is a constant; \( h_0 \) and \( h_1 \) are the multi-resolution filter coefficients used for decomposition[7]. The wavelet-packet reconstruction algorithm is as follows:

\[ d_i^{i+1,n} = \sum_k [h_{0(l-2k)} d_k^{j,2n} + h_{1(l-2k)} d_k^{j,2n+1}] \]  

(3)

As a linear time-frequency analysis method with high self-adaptability to time-frequency localization and signals, the wavelet-packet algorithm is effective in decomposing all time-varying signals[8].

3.2. Methods

When wavelet packets are used to analyze acoustic signals, the decomposition levels are dependent on the working frequency bands and signal characteristics of the test instrument used. As the minimum working frequency of USB-2405 is 1Hz while the frequency of target acoustic signals is generally limited to 1000Hz, according to the sampling theorem [9], the signal sampling frequency was set at 2048Hz, and the Nyquist frequency was 1024Hz accordingly.

According to the wavelet-packet decomposition algorithm, binary scaling was used to decompose the analyzed signals to Level 8. Tab.1 lists the frequency bands of the reconstructed signals by level after decomposition. Here, \( S_{ij} \) is the reconstructed signal of wavelet-packet decomposition coefficient \( j, i=1,2,\ldots,8; j=0,1,2,\ldots,2^i-1. \)
Table 1. The range of frequency bands of reconstructed signal by wavelet packet decomposition.

| Level | $S_{i,0}$ | $S_{i,1}$ | $S_{i,2}$ | ... | $S_{i,j-1}$ | $S_{i,j}$ |
|-------|-----------|-----------|-----------|-----|-------------|-----------|
| 1     | 0—512    |           |           |     | ...         | 512—1024  |
| 2     | 0—256    | 256—512  | 512—768  |     | ...         | 768—1024  |
| 3     | 0—128    | 128—256  | 256—384  |     | ...         | 768—960   |
| 4     | 0—64     | 64—128   | 128—192  |     | ...         | 896—960   |
| ...   | ...       | ...       | ...       |     | ...         | ...       |
| 8     | 0—4      | 4—8      | 8—16     |     | ...         | 1016—1020 |

From this, after 8-level decomposition, $2^8$ equally wide bands each spanning $1024/2^8$ are generated. According to the Parseval theorem [10], the wavelet-packet energy spectrum of an acoustic signal is:

$$E_{s,j} = \int |S_{s,j}(t)|^2 dt = \sum_{k=1}^{m} |x_{j,k}|^2$$  \hspace{1cm} (4)

where: $x_{j,k}$ ($j=0,1,2,...,2^8-1; k=1,2,...,m$, $m$ is the number of samples at the discrete point of signals) is the amplitude of the discrete point of reconstructed signal $S_{s,j}$. Assuming the gross signal energy is $E$, then:

$$E = \sum_{j=0}^{2^8-1} E_{s,j}$$  \hspace{1cm} (5)

The percent of energy per frequency band in the gross signal energy is:

$$P_{s,j} = \frac{E_{s,j}}{E} \times 100\%$$  \hspace{1cm} (6)

4. Energy characterization of battlefield blasting noises

Figure 4, 5, and 6 show the time domain waveforms of one acoustic signal sample of the rifle shooting, explosive blasting, and WAV in motion, respectively, from the signal database acquired during the experiment. Here, the X-axis $n$ is the sampling point and the Y-axis is the normalized amplitude.

From these waveforms, we can see abrupt amplitude variation in the shooting and blasting noises featuring short duration that is similar to pulse signals.

Figure 4. The acoustic signal of rifle shooting

Figure 5. The acoustic signal of TNT blasting
Figure 6. The acoustic signal of WAV

The db8 wavelet base was used to decompose the Level-8 signals on the Matlab platform, and the percent energy per frequency band in the gross signal energy was derived using the computation program compiled from formula (4) ~ (6), as shown in Figure 7.

Figure 7. The energy spectrum distribution for the signals of each acoustic source

From these charts:
1. The rifle shooting signals have a wide energy spectrum, covering a frequency range of 20Hz~1000Hz. The main energy appeared in the 36Hz~64Hz band, and the peak value was nearby 44Hz;
2. The energy of the TNT blasting signals mostly appears below 520Hz, and is typically in the 36Hz~128Hz and 196~224Hz ranges. The main energy band is fairly broad: 40Hz~116Hz, and the peak value was nearby 68Hz;
3. The WAV signals show a narrower energy range and are mostly less than 250Hz. The energy typically appears in the 84~128Hz range and the peak value is nearby 128Hz.

The energy features of similar acoustic signal samples were investigated. Five samples selected for each acoustic source were computed and analysed using wavelet-packet energy method. Table 2 lists the frequencies at which the peak energy frequencies of individual samples appeared.

Table 2. The corresponding frequencies at peak energy values for the acoustic source samples

| S/N | Rifle | Acoustic Source | WAV |
|-----|-------|-----------------|-----|
| 1   | 68    | 68              | 128 |
| 2   | 40    | 76              | 124 |
| 3   | 48    | 68              | 128 |
| 4   | 68    | 80              | 128 |
| 5   | 40    | 76              | 124 |
From the Table 2, the peak energy values of the rifle shooting signals are mostly found in the 40Hz~48Hz range, those of the TNT blasting signals are in the 68Hz~80Hz range, and those of the WAV signals are typically nearby 124Hz~128Hz. Analysis reveals relatively stable frequencies at peak energy values among similar acoustic sources and quite distinct frequency variations among different acoustic sources.

The figures indicate that, in the wavelet-packet energy spectra for the rifle shooting and TNT blasting signals we studied, the main peak positions are quite stable, and the regions where the spectral peaks of signals are concentrated are significantly different. The resulting energy features of other acoustic samples were compared with the energy features of the WAV signals as the target signals using the frequencies at the peak energy values as the signature indicators. The result shows relatively stable energy features among different acoustic sources and significant variations among them. These parameters featuring relative intratype stability and significant intertype variability can be used as the signature parameters for acoustic target recognition and used for subsequent classification and recognition.

5. Conclusion
The energy characteristics of two types of battlefield blasting signals and a type of WAV acoustic signals are analyzed using the wavelet-packet energy method. The result indicates that energy analysis based on wavelet packets is able to mining the energy features of some kinds of acoustic signals. The frequencies at peak values are similar among similar acoustic samples while those are quite different among different acoustic samples. This suggests that the wavelet-packet energy method is effective in describing the characteristics of battlefield blasting noises and WAV acoustic signals as the signature parameters for classification and recognition.

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