Research on Propagation Characteristics of Seismic Signal for Moving Armoured Targets

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Abstract. This paper is focused on the Seismic Signal characteristics of wheel and track vehicles. The effect of vehicle speed of these two vehicles on the Seismic Signal was studied through experimental and theoretical methods. The Seismic Signal s of these two vehicles with two different speeds were tested firstly. Then the measured signals were analyzed by means of the power spectrum method and the wavelet transform method, respectively. And the time- and frequency domain features of the signals were obtained subsequently. Finally, the influence of the speed and type of vehicle on the time- and frequency domain features of the signal and its propagation characteristic were investigated. The results show that, with the propagation of vehicle speed and distance, there is a similar varying law of the Seismic Signal for different vehicles. However, the difference of the time- and frequency domain feature between the two vehicles are striking.

1. Introduction
When vehicles, people and other targets move on the ground, they will cause the vibration of the surface medium particles and generate seismic signals, which can be detected and identified[1]. The ground motion characteristics of maneuvering targets are an important characteristic for target recognition[2]. At present, domestic study mainly focus on the feature extraction and recognition of single-point signal[3] and feature fusion recognition of multi-node signals[4], few reports on the propagation characteristics of the ground motion field caused by the target movement[5]. The study on the propagation characteristics of the target ground motion plays a decisive role in the identification algorithm construction and the node topology design of the distributed ground motion detection system.

For the above reasons, this paper studies the propagation characteristics of seismic signal s for two types of moving ground armored based on the measured signals in the field. A multi-node signal test scheme is designed, using power spectrum and wavelet transform methods to analysis the time-frequency of the measured target seismic signals, and the time-frequency characteristics and propagation attenuation characteristics of two types of target seismic signals are obtained.

2. Field test of target Seismic Signal
The Seismic Signal s generated by the tracked armored vehicles and wheeled armored vehicles in a certain area were collected separately. The test field is sand with part of grass. Three sensor nodes were set up in a straight line perpendicular to the target moving path, and the Seismic Signal s of the two
targets were tested at two different speeds (working condition A: 15km/h and working condition B: 30km/h). The layout of the test field is shown in Figure 1.

![Fig.1 Layout map of the test field](image1)

![Fig.2 Data collection system](image2)

The Seismic Signal acquisition system is vibration sensor CDJ-Z, signal amplifier SCB1002-2024, acquisition instrument USB-2405 and portable computer, etc. The layout is shown in Figure 2. The vibration sensor is inserted into the ground by the nail, the amplifier with sensitivity of the 1V/cm/s is set to 1000 times and without bandpass filtering; the sampling frequency of the signal acquisition instrument is set to 10240Hz. A total of 36 groups of valid sample signals were got in the test.

3. Analysis of characteristics of target Seismic Signal propagation

The power spectrum and wavelet transform method are used for calculation and analysis for the measured signal. Power spectrum estimation (PSD) is to estimate the power spectrum of a signal with finite length data, that is estimate the power spectrum density of a stationary random signal with fixed N sample data. Wavelet transform is a time-frequency localized analysis method with fixed size but changeable time, frequency and shape. It has higher frequency resolution and lower frequency in the low frequency part and has a higher time resolution and a lower frequency resolution in the high frequency part.

3.1. Analysis of measured signals of wheeled armored vehicles

3.1.1. Signal propagation characteristics analysis under working condition A

Figure 3 shows the time-domain signals at three measurement points when the wheeled vehicle is moving at a speed of 15km/h. They are the Seismic Signal s received at collection point 1, 2 and 3 from top to bottom. The unit of abscissa is s and ordinate is V.

![Fig.3 Time domain signals of wheeled vehicles at three measuring points in the condition A](image3)

Figure 4 shows the power spectrum distribution of the signals at the three acquisition points in the frequency domain. The main frequency band of the signal of collection point 1 is distributed in the range of 7Hz~18Hz, and the main frequency is around 15Hz; the main frequency band of the signal of collection point 2 is distributed in the range of 7Hz~15Hz, and the main frequency is 12Hz; the main frequency of collection point 3 is more concentrated and around 10Hz. So as the distance increases, the main frequency of the signal attenuates and the main energy shifts to the low frequency. The three signals have partial peaks below 4 Hz, which should be caused by low-frequency noise.
The time-frequency diagram results obtained by wavelet analysis and calculation of the measured signals at three points are shown in Figure 5. It can be seen that the energy of collection point 1 is mainly concentrated in the range below 20Hz and the energy concentration band is 15Hz, which is consistent with the power spectrum result; the spectrum distribution of collection point 2 is similar to the power spectrum result, and the main energy is also concentrated around 12Hz. However, since the peak energy is not as strong as the acquisition point 1, some energy can be seen around 2 Hz. This is more clearly reflected in the spectrogram of the collection point 3 with the farthest vertical distance, obviously we can see an energy band at 10 Hz. The energy bars of the 3 collection points at 2 Hz are always displayed, which may be caused by background noise.

3.1.2. signal propagation characteristics analysis under working condition B

The power spectrum of the three signals when a wheeled vehicle is driving on a gravel road at a speed of 30km/h shown in Figure 6. In analysis result that the signal frequency band of the wheeled vehicle under the working condition B is also wide and distributed in the range below 35 Hz. An energy spike can be seen at measuring point 1 around 27Hz, at point 2 around 26Hz and at point 3 around 20Hz. At the same time, the three signals have partial peaks below 4 Hz, which should be caused by low-frequency noise.
acquisition point 1 and 2 are mainly distributed around 17 Hz and 27 Hz; the energy of acquisition point 3 is mainly distributed around 16 Hz and 20 Hz. It is obvious that there is an energy band near 3 Hz in the spectrogram of the three collection points besides 10 Hz to 30 Hz, which should be caused by noise.

3.1.3. Signal comparation of wheeled vehicles under two working conditions

In terms of frequency domain signal characteristics, the main frequency of the vibration signal under working condition B is concentrated around 17 Hz compare to A, and the conditions at the three measuring points are consistent. So as the speed increases, the main frequency band of the vibration signal of the wheeled vehicle has a double peak characteristic. As the distance of the measuring point increases, the main frequency of the vibration signal decreases, but it is not obvious. The signal main frequency of working condition B is slightly larger than that of A, indicating that as the speed increases, its main frequency will increase.

In the time-frequency domain signal characteristics. At the collection point 1, the energy-concentrated frequency bands under the two working conditions are similar, but at the collection point 2 and 3, the energy-concentrated frequency band under the working condition A is lower than B. The comparison shows that the higher the vehicle speed, the higher the frequency band where the energy is concentrated.

3.2. Signal propagation characteristics analysis of tracked vehicles

3.2.1. Signal propagation characteristics analysis under working condition A

The crawler-type vehicle is running on a sandy gravel road at a speed of 15km/h under working condition A. The power spectrum of the signals at the three collection points is shown in Figure 8. Analysis shows that the three signal frequency bands are relatively concentrated, mainly distributed in 10Hz~20Hz, and their main frequencies are respectively 17Hz, 17Hz and 12.5Hz.

![Fig. 8 Power spectrum of tracked vehicle at three measurement points in the condition A](image)

Figure 9 is a time-frequency diagram obtained by wavelet analysis of three collection points. At collection point 1 and 2, the main energy is concentrated around 17 Hz and at point 3 is 13 Hz. From the comprehensive analysis of the time-frequency diagrams of the three collection points, it can be seen that under working condition A, as the distance increases, the main energy of the tracked vehicle Seismic Signal attenuates from 17Hz to 13Hz, and the low-frequency component increases.

![Fig. 9 Wavelet time-frequency plots of the signals of tracked vehicles in the condition A](image)
which is in the range of 9Hz~10Hz and the energy is relatively small. Since the measurement point 3 is close to the factory near the test site, it may be caused by factory machinery.

3.2.2. *signal propagation characteristics analysis of tracked vehicles under working condition B*

Figure 10 shows the power spectra of these three signals when the tracked vehicle is running at 30km/h, the dominant frequencies of these three signals are all around 38 Hz in the frequency domain.

![Fig.10](image)

**Fig.10** Power spectrum of tracked vehicle at three measurement points in the condition B

Figure 11 is a time-frequency diagram of wavelet analysis of signals from three collection points of a crawler vehicle under working condition B. Analysis shows that main energy is concentrated in the range of 20Hz to 40Hz. Comprehensive analysis shows that as the distance increases, the main energy frequency band of the tracked vehicle Seismic Signal has been around 38 Hz and the attenuation is small under working condition B. The analysis shows that as the speed of tracked vehicles increases, the main energy frequency band of the Seismic Signal attenuates less with distance and the consistency is higher.

![Fig.11](image)

**Fig.11** Wavelet time-frequency plots of the signals of tracked vehicles in the condition B

3.2.3. *Comparative analysis of tracked vehicles signals under two working conditions*

The signals are roughly the same under the two working conditions in terms of time-domain signal characteristics, indicating that the amplitude of the tracked vehicle vibration signal is mainly determined by the weight of the vehicle rather than the speed.

In terms of signal characteristics of frequency domain, the dominant frequency of the tracked vehicle under working condition B is larger than A. It means that for tracked vehicles, the faster the speed, the higher the main frequency.

In terms of signal characteristics of time-frequency domain, the energy-concentrated frequency band under working condition A is lower than B. The comparison shows that the higher the speed of the vehicle, the higher the frequency band where the energy is concentrated.

3.3. *Comparative analysis of two target signal characteristics*

It is summarized according to the frequency band and energy situation of the two types of targets under different working conditions:

1. The peak amplitude of the wheeled vehicle signal is about 1/2 of the tracked vehicle under the same conditions;
2. The frequency bands of the two target main frequencies are positively related to their movement speeds, the faster the speed, the higher the frequency of the main frequency.
3. The frequency band of wheeled vehicles is wider and more complex, and its energy is relatively dispersed. Under working condition A, most frequency bands below 20 Hz are covered; under working condition B, most frequency bands from 10 Hz to 30 Hz are covered.
(4) For tracked vehicles, the main energy frequency band is relatively concentrated, under working condition A, it is mainly in the range of 10Hz～20Hz; under working condition B, it is mainly in the most frequency band of 35Hz～40Hz.

4. Conclusion
From the study of frequency domain and time-frequency domain quantitative of Seismic Signals of tracked vehicles and wheeled vehicles moving at different speeds on gravel roads, the following conclusions can be drawn:

1) Track vehicle have greater impact on the ground due to their road wheels and tracks, and their signal amplitude is generally higher than that of wheeled vehicles under the same conditions.

2) Track vehicle have greater impact on the ground due to their road wheels and tracks, and their signal amplitude is generally higher than that of wheeled vehicles under the same conditions.

3) As the movement speed increases, the dominant frequencies of the two target signals have an upward trend and energy also shifts to high-frequency components.

4) As the propagation distance increases, the main frequencies of the two target Seismic Signals tend to shift to low frequencies, and the low-frequency component energy gradually increases.

From the study of the frequency band of the main frequency of the vehicle seismic signal and the frequency range of the main energy and the degree of attenuation, it can be used for judging the type of vehicle; in addition, power spectrum analysis and wavelet analysis have important significance for seismic identification and structural design of distributed detection systems.

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References
[1] Yang Wang. 2016 Research on the person and vehicle targets identification method of seismic signal. Harbin Engineering University.
[2] Kai-ming Li, Qun Zhang, Ying Luo. 2014 Review of ground vehicles recognition. ACTA Electronica Sinica, vol 3, pp 538-546.
[3] Kai Du, Xiang Fang, Sheng Zhang. 2018 Feature extraction of vehicle vibration signals based on update lifting morphological wavelet transform. Journal of Vibration and Shock, vol 37(18), pp 135-139.
[4] Qinqin Jiao, Li-yao Niu, Zhuang-wen Sun. 2015 Vehicle recognition based on fusion of acoustic and seismic signals. Microcomputer & Its Applications, vol 34(11), pp 79-82.
[5] Heng Zhang, Zhong-ming Pan, Wen-na Zhang. 2018 Acoustic-seismic mixed feature extraction based on wavelet transform for vehicle classification in wireless sensor networks. Sensors, vol 18(6), p E1862.