Research on the Movement Law of Gravel under Water Based on the Principle of Audio Analysis

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ABSTRACT

Pebble bed-load movement is an important factor to affect the channel scouring and silting, and often causes the navigation obstruction problem. But at present, it is difficult to measure the space-time characters of the pebble movement. That restricts the development of the key mechanism of the navigation obstruction and other relevant research. Hereto we put forward a acoustic method. This method mainly draws lessons from the voice signal processing methods to analyze the common audio signal of field measurement such as pebble, ship and water. Meanwhile, the peak frequency, fundamental frequency and energy distribution characteristics of wavelet transform is extracted as the characteristic parameters for pebble movement, and to the end, the analysis of the synthesis signals is completed on the basis of the characteristic parameters for identifying pebble movement. When comparing the identification result with 12 times of ear recognition, the gap is only one time. It shows that the method has high recognition accuracy and feasibility for observing gravel movement.

KEY WORDS: gravel bed-load; space-time characters; acoustical principle; Characteristic parameters

INTRODUCTION

Part of the rivers in our country, especially in mountainous rivers, the volume of gravel bed-load transport accounts for a certain proportion. Although the proportion is not much, is still an important factor to affect the channel scouring and silting. Effective observation of pebble movement has a very important significance in collecting bed-load information, ensuring the effectiveness of Channel regulation and also enriching and developing the basic theory of bed-load.

However, at present, the observation methods can not be good in monitoring the movement process, spatial and temporal distribution, dynamic deposition characteristics of pebble. Since the condition of the mountainous rivers is very complicated, whether light wave or electromagnetic wave, whose propagation attenuation is very large, is not suitable for large-scale and long-distance detection and information transmission of underwater target. The sound wave has the best transmission properties in water among the various energy forms. Foreign research institutions have successfully used the acoustic observation method to observe the pebble movement and sediment transport, what fully explains the effectiveness and feasibility of the method is much higher than other methods, such as bedload sampler, interpretation method, and tracer technique. The acoustic observation method applies acoustic sensors and recording equipment to measure the sound signal from pebbles collision. According to the observation results, based on speech signal processing technology and combined with pebble motion sound characteristics, we propose a identification and extraction method for pebble movement in natural river.

SIGNAL PRETREATMENT

Target signal detection and extraction

The original sound signal usually contains the target signal that we need to analyze, and also contains the background sound that we don't need. If the target signal can be detected and extracted from original signal, then it can greatly reduce the workload and improve the accuracy of the result.

Pebble collision or other mutations sound (such as a ship sound) occurs in the original signal will cause the change of energy. According to the change, we can judge that the time of the target signal occurs. For example, the Figure 1a contains three times collision, Fig. 1b is the change of energy, with three times corresponding mutations.

The maximum energy of the background sound is the threshold value, then the time period of which energy is greater than the threshold value is regarded as the objective signal segments. After that, each target signal segments individually can be extracted, as shown S1, S2, S3 in Fig. 1C. Eventually the original signal is classified as short clips to analyze.
Background sound is the sound that always exists in the whole audio signal, such as the sound of the water. Its presence may cause serious interference to the analysis result, so in order to get obvious sound units except background sound, and to compress the amount of data, it is necessary to reduce and eliminate the data before analyzing the background sound. In this paper, spectral subtraction method is used to reduce the background noise of the experimental signal of the flume with the background of the sound. Spectral subtraction is the most common method of speech denoising, and its basic thought is it calculates by subtracting the spectrum of the noise signal from a spectrum of the original signal. Herein the time sequence of speech signal is set to be \( x(n) \), the speech signal at \( i \)th frame after Framing windowing is set to be \( X_i(n) \) and the frame length is \( N \), the basic spectral subtraction algorithm is:

\[
\hat{X}_i(k) = \begin{cases} 
X_i(k) - a \times D(k) & X_i(k) \geq a \times D(k) \\
\frac{b \times D(k)}{} & X_i(k) < a \times D(k)
\end{cases}
\]

(1)

Where \( |X_i(k)| \) is the energy of each frequency after Fourier transformation of original signal, and \( D(k) \) is the average energy of each frequency for precursor without signal, moreover \( |\hat{X}_i(k)|^2 \) is the energy of each frequency after spectrum subtraction. Wherein \( a \) and \( b \) are two constants which are referred to as over-subtraction factor and gain compensation factor.

After spectral subtraction the amplitude is \( |\hat{X}_i(k)| \), and then, we may obtain the sound signal sequence via inverse Fourier transform. In the process, we select the time for precursor without signal as 0.5s before the pebble movement, as shown in Fig. 2a, in addition, the audio signal of the flume experiment is reduced by the spectral subtraction and the waveform is shown in Fig. 2b.

**Fig. 1 Extraction of target signal**

**Reduction of environmental background noise in pretreatment**

**Fig. 2 Comparison of waveform before and after noise reduction**

**SOUND CHARACTERISTICS ANALYSIS**

**Peak frequency**

The transform spectrum, which can reflect the characteristics of the signal in frequency domain, will be obtained after Fourier transform. There are 3 schematic diagrams of sound signal frequency spectrum respectively for pebble, ships and water (where \( f \) is the frequency, and \( E_n \) is the energy).
The position of maximum energy in the spectrum is different in the three kinds of signals, for a more detailed description of it, the pebble is around 3200 Hz, the ship is in the 100Hz or so, and the water is at about 25 Hz (Fig. 3). This difference may be related to the material and the internal structure of the signal itself, so we can put the spectrum diagram energy corresponding to the maximum frequency as a feature of the signal, and it is called the peak frequency. (so it can be used as a characteristic of the signal, which is the maximum value of the energy in the frequency spectrum is called the peak frequency.) In this paper, the sample size of collected sound, such as pebble, ship and water, are 300, 100 and 200, respectively. The peak frequency of these sound are statistically analyzed, and the probability density distribution curve of the peak frequency is obtained (Fig. 4).

There is a obvious difference of peak frequency distribution among Pebble, ship and water. For a more detailed description of it, the peak frequency of pebbles, which is influenced by particle size and material, is in the 1000 ~ 5000 Hz. Ship's peak frequency mainly ranges from 25 to 500 Hz, and it is affected by ship type. The peak frequency of water is between 20 to 30 Hz. Therefore, the peak frequency can be used as a standard for the pebble identification.

**Fundamental frequency analysis**

Sound is produced by the vibration of the object, and the reciprocal of the vibration period is called the fundamental frequency, which is an important parameter in speech recognition. There are abundant methods to extract pitch, such as average magnitude difference function method (AMDF), center clipping (auto-correlation function, ACF), Cepstrum method (CEP), Linear prediction method (Atal), and so on. Wherein the auto-correlation method is widely employed, even is one of the most practical and reliable method. The basic idea is that if the two signal waveform is completely different, the correlation function is close to zero. On the contrary, if the two signal waveform is the same, a peak will appear in the lead and lag spikes.

Signal is set as $x(n)$, then the auto-correlation is defined as

$$\phi(k) = \sum_{m=-\infty}^{\infty} x(m)x(m+k)$$  \hspace{1cm} (2)

Where $k$ is the retardation.

If the sound signal has a period, then it will obtain the maximum value at $k=0, \pm p, \pm 2p, \cdots$. Due to the pebble collision signal is not purely cyclical, a peak will appear instead of the maximum value in the pitch. Soon afterwards, we need to analyze auto-correlation function for the sound of pebbles, ship and water (Fig. 5).

Give statistical analysis to the pitch frequency of the three kinds of signals, and display the probability density distribution:

The pebble pitch frequency is between 2000 ~ 4000 Hz. The pitch frequency of ship, which is affected by the type of the vessel, concentrates between 100 ~ 1500 Hz. The Water pitch frequency is in about 25 Hz, very close to its dominant frequency (Fig. 6). It follows that the pitch frequency characteristics of Pebble is significantly different from other two kinds of sound, and so pitch frequency can be used to identify the pebble voice.

**Energy distribution characteristics after wavelet transform**

Wavelet transform can decompose the signal at multiple scales, and then we get the coefficient collection of subspace in various scales. The wavelet coefficients reflect the energy information that can provide the time-frequency local features of original signal, especially in different frequency bands. Since the amount of information of the wavelet coefficients when they are directly being as the characteristic value is too large, so we need to focus solution of signal energy on
various scale, and to appoint them as identification parameters. This is the basic principle of energy characteristic value based on wavelet transform.

The order of wavelet transform is J. The detail information of each scale (high frequency coefficient) and the approximate information of the last layer (low frequency coefficient) are combined into the calculation formula:

$$E^d_j = \frac{1}{E} \sum_{k=1}^{j-1} D^2_{jk}, \quad j = 1, \ldots, J$$

(3)

$$E^a_j = \frac{1}{E} \sum_{k=1}^{j} A^2_{jk}$$

(4)

Where $$E = \sum_{j=1}^{J} f^2_j = E_x^e + \sum_{j=1}^{J} E^d_j$$, j is the corresponding scale.

Subsequently, the energy characteristic vector of J scale can be obtained:

$$T = \left[ E^d_1 \ E^d_2 \ E^d_3 \ldots E^d_J \right]$$

(5)

Herein we select "db5" as the wavelet basis function and take order for wavelet transform as 6, by testing and analyzing multiple sets of wavelet function and order of wavelet transform. In order to ensure the comprehensiveness of the data, the sample size of collected sound, such as pebble, ship and water, are 300, 100 and 200, respectively. The energy eigenvector and the average feature vectors of all signals are obtained. (Fig. 7).

![Fig. 7 The energy distribution of the three signals](image)

The primary difference among three kinds of signal energy distribution is embodied in:

1. The energy of pebble sound focuses on the high-frequency coefficients in the order of 1 to 3, which exceeds 80% of the total energy, and the energy of the low frequency coefficient does not exceed 10%.
2. The Ship's sound energy mainly concentrated in the low frequency coefficients and high frequency coefficient in the order of 4 to 6.
3. More than 90% of the water sound energy is concentrated on the low frequency coefficient.

Above all, the distribution range of characteristic parameter of the pebble movement can be obtained by comparing the difference among the pebble and the other two kinds of sound signal. The confidence level of confidence interval is determined as 0.8, and then the pebble peak frequency is in the range of 1400 ~ 4000 Hz, and pitch frequency range from 2000 to 3800Hz. The energy distribution of the wavelet transform of the pebble. For pebble, the total energy of the high frequency coefficients in order of 1-3, can be used to characterize the energy distribution of wavelet transform. The total energy is denoted by T and should satisfy $0.8 < T < 1$.

IDENTIFICATION EFFECT ANALYSIS

In order to verify whether the characteristic parameters can describe the pebble movement sound, in this paper, synthetic analysis of the complex audio signal plays an role in identifying the recognition effect. The synthetic signal contains a series of complex sound signals, such as the sound of water, ship's navigation, pebble movement, and thunder, etc. The figure 8 is the time-domain waveform.

![Fig. 8 The time-domain waveform of the synthetic signal](image)

There are 677 pieces of sound clips after completing the detection and extraction for the target signal. And then the distribution characteristic of each sound segment will be represented by a vector $(f^1, f^2, T)$, where $f^1$ is the peak frequency, $f^2$ is the fundamental frequency and $T$ is the energy distribution through wavelet transform (Fig. 9).

![Fig. 9 The distribution characteristic of each sound segment](image)

The blue rectangle in the figure is the characteristic distribution region of the pebble moving.

In the 677 pieces there are 11 pieces of sound segment falling in the region. It indicates that the synthesis signal has 11 times of pebble collision. Comparing the recognition result with 12 times of ear recognition, the gap is only one.
CONCLUSIONS AND OUTLOOK

Part of the rivers in our country, especially in mountainous rivers, pebble bed-load movement often causes navigation obstruction. But at present, it is difficult to measure the space-time characters (time, quantity, etc.) of the pebble movement. That restricts the development of the key mechanism of the navigation obstructing and other relevant research. Therefore, this research focuses on the acoustic method, and expects to obtain the real and reliable pebble motion data through more convenient methods.

The research is starting from the identification of pebble movement and then draws lessons from the voice signal processing methods to analyze the common audio signal of field measurement such as pebble, ship and water. Meanwhile, the peak frequency, fundamental frequency and energy distribution characteristics of wavelet transform is extracted as the characteristic parameters for pebble movement, and to the end, the analysis of the synthesis signals is completed on the basis of the characteristic parameters for identifying pebble movement. The main conclusions are as follows:

(1) For the background noise in the field measurement, it can be reduced and eliminated by using Boll spectral subtraction method. At the same time, in order to reduce the workload, the time period of energy mutation is extracted and analyzed according to the energy change.

(2) The characteristic parameters of the pebble movement about the peak frequency, the fundamental frequency and the energy distribution after wavelet transform are obviously different from the ship and water. The pebble peak frequency is in the range of 1400 ~ 4000 Hz, and pitch frequency ranges from 2000 to 3800Hz. The energy of pebble sound focuses on the high-frequency coefficients in the order of 1 to 3, which exceeds 80% of the total energy.

(3) On the basis of the characteristic parameters for identifying pebble movement, the analysis of the synthesis signals is completed, and 11times of pebble collision is extracted from 677 pieces. Comparing the recognition result with 12 times of ear recognition, the gap is only one. It shows that the method has high recognition accuracy.

In summary, the acoustic method is simple and convenient to operate, and reliable on measurement results. For observing the gravel movement, this method is feasible.

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