Embedded extraction method based on characteristic frequency of wavelet transform frequency shift signal

Lei Zhu, Jihong Shen

Harbin Engineering University,
Heilongjiang, Harbin, 150001, China

Abstract
As the train speed and density is great improved, the passing ability and transportation safety of train during the transmission play an important role on the high efficiency and normal operation of whole rail net. How to quickly, accurately and reliably demodulate characteristic information of the track frequency-shift signal (FSS) will have a direct impact on train punctuality and safety, it's also the current development direction of the track FSS demodulation. Noticing the ridge features of the FSS showed on transform domain, wavelet ridge technology was employed to extract characteristic parameters for the signal UM71, and the effectiveness of using wavelet ridge to extract FSS was also verified.
Key words: TRACK FREQUENCY-SHIFT SIGNAL, FILTER-ENVELOPE TECHNOLOGY, WAVELET RIDGE, TRACK CIRCUIT, SIGNAL UM71

1. Introduction

In the field of in-vehicle safety and monitoring technology, countries with well-developed fully develop equipment status monitoring technologies adapted to their national railway safety, operating management as well as the design and manufacturing characteristics. A large quantity of statistics shows that promoting the use of monitoring devices foregrounds the operating safety effect of trains [1-3]. As a new generation of monitoring device, LKJ2000 has been greatly improved in technical grade, function, performance, reliability and other aspects with comparison of previous generation of LKJ-93 and JK-ZK. However, with the development of railway transportation, the growing demand of traffic safety, the increased equipment requirements of traffic safety as well as the increased equipment requirements of complexation and function expansion of various technical devices, there also exist deficiencies in the LKJ2000, which need to be improved and upgraded [4]. There also exist deficiencies in the software of LKJ2000. For instant, error correction phenomenon occurs during the monitoring period and there exists specific uncertainty between the error-corrected stations and vehicles in the LKJ2000. That is to say, although a vehicle has ran for a long time without any problem, an occasional error correction at a certain station could lead to the uncertainty of time and the vehicle whether in the common frequency shift or exchange counting [5]. Sometimes, the LKJ2000 monitoring has been corrected when passes the distant signals, but there also exists some distance errors that need to be manually adjusted by drivers when passes the starting signals. These phenomena are mainly caused by the inaccurate or error judgment of insulation joints when there has processing signal of ground information board.

Instantaneous frequency variation of the progressive signal reflects the important features of the signal, and it is the key parameter of the signal model. So choosing a suitable transform domain to extract the instantaneous frequency information of the signal, and selecting the appropriate method for FSK reconstruction are problems to be discussed in this paper. Methods of using a ridge feature of signal showed in the transform domain to extract the instantaneous frequency information appeared in the 1990s, the core idea is: signal meeting certain conditions in the continuous wavelet transform domain (or other linear transform domain) whose parameters distribution presents characteristics of the ridge; theoretical analysis shows that between the parameters and the original signal distributed along the ridge line has a strong similarity, important parameters can be used to describe the original signal, the data ups and downs distributed on the ridge line and the position of the ridge has actual physical significance [6-8], correspond directly with the instantaneous variation of the signal amplitude and signal frequency [9-12].

In this paper, FSK is demodulated by the method of combination with wavelet analysis and spectral analysis. The band-pass filtering of FSK is conducted by the band-pass filtering function peculiar to the wavelet transform. Upon selecting appropriate wavelet basis and decomposition level, the carrier frequency and low-frequency control signal of FSK can be obtained through the spectral analysis and counting of level signal with signal characteristics. The instantaneous characteristics of FSK are extracted by the wavelet-ridge. The phase angle of FSK is formed through Hilbert transform, the wavelet ridge is obtained by taking advantage of the phase angle iteration and the instantaneous frequency of the signal is obtained then. Among the frequency changes, the low-frequency control signal of FSK by counting. Experimental results show the advantages of the algorithm.

2. Track Arequency-shift Signal Analysis

Track frequency-shift signal analysis $\overline{S}(t) = A_0 \exp\left[j\theta(t) \right]$, among them, A_0 is the FSS amplitude, $\theta(t)$ is the FSS instantaneous phase, change of FSS A_0 along the time axis is slower than change of FSS instantaneous phase $\theta(t)$ So $S(t)$ meet the progressive conditions.

$$\left| \frac{d\theta(t)}{dt} \right| \geq \left| \frac{1}{A} \frac{dA_0}{dt} \right| \quad (1)$$

So FSS signal can be decided to be a progressive signal.

Compared track frequency shift signal $S(t)$ with the corresponding analytic signal $S(t)$, Fourier spectrum to which analytical signal corresponding in the positive axis is identical to the FFT spectrum of the original signal, the amplitude is twice of the Fourier spectrum of the original signal while the spectrum of analytical signal in the negative axis is zero. For a real signal $x(t)$, the Fourier spectrum on the positive and negative half of axle is completely symmetrical; leaving only the positive half of the spectrum contains all the information of the signal. Therefore, the use of analytical form of a real signal in theoretical analysis, you can simplify the analysis, to make the results more vivid and prominent.

3. Wavelet ridge Extraction and calculation Method of Track Frequency-shift Signal

Wavelet transform basic ideology is making use of cluster basis functions to denote or approach analytical signal. For the given signal $S(t)$, the corresponding continuous wavelet transform CWT is defined as:

$$W_f(a,b) = \left\langle S, \psi_{a,b} \right\rangle = \int_R S(t)\overline{\psi}_{a,b}(t)\,dt = a^{-1/2} \int_R S(t)\overline{\psi}\left(\frac{t-b}{a} \right) dt \quad (2)$$

In the formula, a is ruler factor, $a \in R^+, b$ is the panning factor: $\psi_{a,b}(t)$ is educed from wavelet function $\psi(t)$ by panning b and stretching a, is called wavelet function. $\overline{\psi}_{a,b}(t)$ is the conjugate functions of $\psi_{a,b}(t)$.

During the research of wavelet, some appropriate wavelet function was found such as: Haar wavelet, and spline function etc. They all have their own application field. The main target of this thesis is to do the time - frequency analysis track of frequency shift signal, and therefore wavelet should be selected in the time domain and frequency domain has a good localization characteristic. By uncertainty theorem it's known: impossible to obtain a window function window area which is less than or equal to Gaussian function as a window function. Therefore, this article selected Morlet wavelet having a good aggregation in time and frequency domain, and which is complex-valued, and its function expression is:

$$\psi(t) = \exp\left(\frac{-t^2}{2} + j\omega_0 t\right) = A_\psi(t)\exp\left[j\varphi_\psi(t)\right] \qquad \omega_0 \geq 5$$

(3)

Due to the track frequency shift signals and Morlet wavelet function is progressive in nature, based on wavelet defining equation (3), can obtain that continuous wavelet transform of a progressive signal and wavelet analysis formula is

$$W_f(a,b) = < \overline{S}(t), y_{a,b} >$$
$$= a^{-1/2}\int_R A_0 \exp\left[jq(t)\right] A_y\left(\frac{t-b}{a}\right)\exp\left[jf_y\left(\frac{t-b}{a}\right)\right]dt$$
$$= a^{-1/2}\int_R A_{a,b}(t)\exp\left(jf_{a,b}(t)\right)dt$$

(4)

$$A_{a,b} = A_0 A_\psi\left(\frac{t-b}{a}\right), \psi_{a,b}(t) = \theta(t) - \varphi_\psi\left(\frac{t-b}{a}\right)$$

Make a gradual expansion on the term of equation (4) on the right and keep only one of them-order item, you can get an approximate expression of wavelet coefficients

$$W_f(a,b) \approx \left(\frac{\pi}{2}\right)^{1/2} \frac{e^{j\frac{\pi}{4}\mathrm{sgn}\left(\varphi^{\pi}_{a,b}(t_s)\right)}}{\sqrt{\left|\varphi^{\pi}_{a,b}(t_s)\right|}} \overline{S}(t_s)\frac{1}{a}\overline{\psi\left(\frac{t_s-b}{a}\right)} \qquad (5)$$

From the formula (5), when $t_s(b,a) = b$, formula (4) can get a part maximum value. At the maximum point, it is recorded as $a_r(t)$, the point collection $t_s(b,a) = b$ whose definition meets the $(b, a_r(b))$ is called the ridge of the wavelet transformation. The curve made by $\{(a,b) | a = a_r(b)$ is called wavelet ridge line. In those special points, compare and analysis with wavelet through ruler transformation, its frequency is identical with the instant frequency of the signal at this moment. It makes the wavelet parameters distributed in the special points can be used to denote all the information of the original signal.

Wave change is $W_f(a, kT)$,among them, k =1,2,…..is the Temporal variables, T is the sampling intervention, it is also marked as $\tau_a(k)$ which is the phase of the wavelet transformation . D_b Is the discrete differential operator at b place? The iterative formula of extracting wavelet ridge by phase is the specific calculation methods are as follows:

$$a = \frac{\omega_0}{D_b(\tau_a(k))} \qquad (6)$$

Select the primary value according to the estimation and experience $a = 0, a = a_0, k = 0$

Make iterative formula $a = \omega_0 / D_b(\tau_a(k))$

If $|(a_t - a)/a| < \varepsilon$,(ε is set as small positive number), $a_\tau(k) = a, k = k+1$ or $a = a_1$

Repeat 2) until finishing all the points need calculating.Procedure Process plan is as Figure 1.

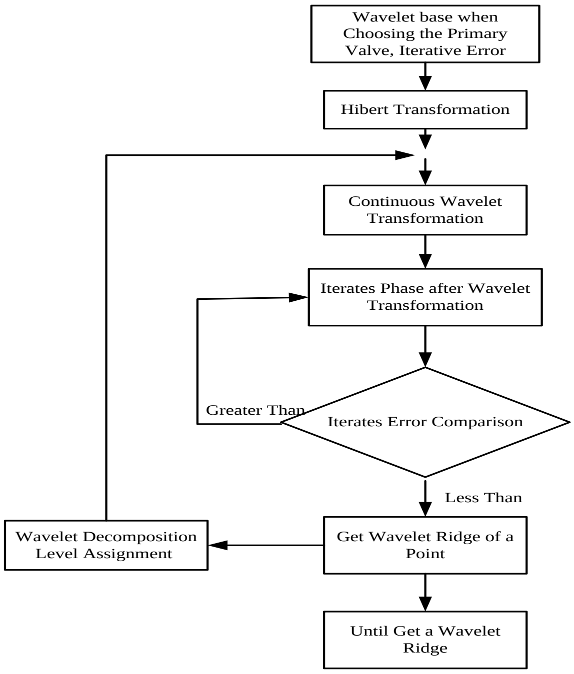


Figure 1. Wavelet ridge extraction process plan

Practicality of wavelet ridge extraction by phase proves well, often only a few iterations can converge. At the same time the number of iterations is related with the selected ε, whereas the size of ε is inversely proportional to the accuracy of the extracted wavelet ridge, so ε should be defined according to the specific accuracy. If the actual signal frequency range is wide, directly to the real frequency of the signal is calculated by the iterative algorithm ε not selected, and therefore the calculation process can be assumed that the sampling frequency is 1, and then calculate the frequency of the signal sampling frequency normalized to strike the actual signal is multiplied by the actual results of the future as long as the sampling frequency can get the actual signal frequency. After wavelet ridge is obtained, by (7) equation where the instantaneous frequency of the signal can be obtained.

$$f_k = \frac{1}{2\pi} \cdot \frac{\omega_0}{a_r(k)} \qquad (7)$$

4. Simulation and Discussion

In this paper, the feasibility of using simulated signals and measured signals UM71 to extract the wavelet ridge characteristic frequency for verification. This section is a condition in Matlab simulation UM71 frequency shift track signal simulation of the signal carrier frequency of 2000Hz, low frequency control signal frequency is 18Hz, the offset frequency is 11Hz, the sampling frequency is 8000Hz, the sampling time is 0.2s, its waveform As shown in Figure 2. Wavelet ridge iterative algorithm, compared to other algorithms, its computing is a small amount, the number of iterations is less, the following gives a brief introduction of its specific practices using iterative algorithm to do iterative calculations:

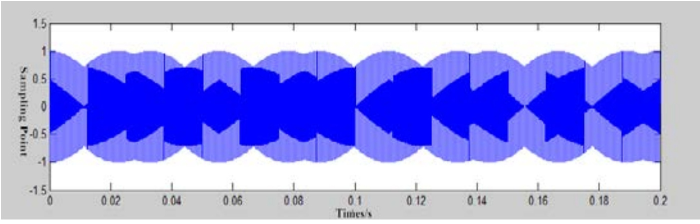


Figure 2. UM71 Simulation signal oscillogram

First, the initial values a_0 , different initial values for any selected point at the beginning of iteration only have a very small error, the calculation accuracy of the subsequent impact. After iteration calculated wavelet ridge, shown in Figure 3. Since accurate extraction phase extraction ridge, suitable for a single ridge, and track frequency shift signal ridges are similar square wave, the frequency of mutations in the presence of the phenomenon can only think it is a single stage ridge, plus the presence of edge effects. Therefore, when extracting wavelet ridge, wavelet ridge corners exist small amounts of glitches.

Secondly, make use of formula (7) to obtain the track carrier frequency shift signal instantaneous frequency, as shown in Figure 4. Calculate the instantaneous frequency graph there is a certain relative error, which is due to the presence of small burr ridge wavelet extraction sake of its corners, and the smoothness of the wavelet ridge corners but also with the size of the iteration error ε values for. ε made smaller, the greater tends to smooth the corners of the burr, the smaller the relative error, but the selection of ε is too small, the amount of calculation will be greatly increased, and the relative error ε is not a linear relationship with. So choose ε value to be based on the actual circumstances, this emulation select ε value 0.00003.

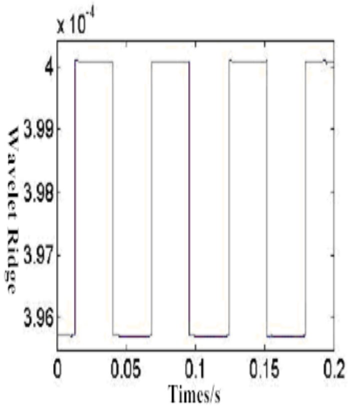


Figure 3. Extracted wavelet liner diagram

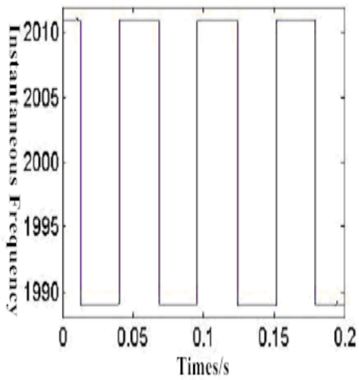


Figure 4. Instantaneous frequency diagram

Finally, from the extraction orbit frequency shift signal instantaneous frequency diagram square wave can be obtained directly by counting method frequency 17.9978Hz, is the low frequency control signal frequency, as shown in Figure 5, the relative error is much less than 0.5%, demodulation accuracy meets the requirements of railway communication systems. The wavelet ridge iterative algorithm although there is some noise-canceling capability, but when you make a lot of noise interference iteration fails. Therefore, in practical application should be pre-filtered to smooth the signal, to prevent the failure of iterations.

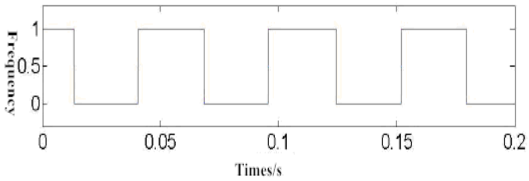


Figure 5. Low Frequency Control Signal oscillogram

4.1. ω_0 Value Setting Problem

As above-mentioned, Morlet wavelet doesn't strictly meet the permit conditions, and only at the center frequency of Morlet mother wavelet function is large enough to meet the conditions approximately. Generally speaking, the bigger ω_0 it is, the more accurate it is. But if ω_0 is too big, it will cause iterative algorithm does not converge. So ω_0 should be selected according to the actual conditions. This thesis chooses ω_0 =5, the calculation can ensure the relative accuracy.

4.2. Marginal Effect of Wavelet Ridge

When the extraction of wavelet ridges by phases, it is suitable for a single ridge extraction. And because of the inaccuracy of signal frequency and the initial value of the mutation, will make the signal at the beginning of each ridge and there is little jitter point mutation. In particular, the end of the signal, the signal points to reduce the error to extract the ridge will increase, even iteration fails. This is relevant with selected Morlet wavelet length calculation. Therefore, the extracted wavelet ridge and instantaneous frequency does not cover the entire time zone.

Iterative algorithm definitely need to set a time when the early iterations, the actual calculation shows that the choice of different initial values for the calculation of the beginning of the accuracy of the impact is very small, but it will affect the calculation time began. Select the iterative error is smaller, the greater the amount of calculation, the higher accuracy, and even the whole phenomenon extract the instantaneous frequency shift will occur. But too much choice when error occurs extract the instantaneous frequency accuracy is not high, even failure.

5. Algorithm Verification

The main parameters of the collected signal carrier frequency 2000Hz, frequency deviation 11Hz signal, low-frequency modulation frequency 15.8Hz, sampling frequency of 8192Hz. Since the measured signal frequency there are some errors, the actual signal is 1985Hz ~ 2009Hz. The feasibility of extracting characteristic frequency wavelet ridge fully described in this section with four sets of railroad scene UM71 actual collection frequency shift track signal was sampled data validation, sampling time these four groups were sampled data 0.25s groups, 1s and 5s of a group, use the following four groups of sampled data for algorithm verification.

5.1. Algorithm Verification of First Group 0.25s Sampling Data

Using Matlab to import railway measured data, the number of samples taken is 2548 points, its time-domain waveform shown in Figure 6, the signal after filtering, the waveform shown in Figure 7. In order not to affect the extracting accuracy of the instantaneous frequency, remove the sampling points before 500 points the signal after filtering, retain 2048 samples points. Thus, extract the signal using wavelet ridge characteristic frequency signal sampling points actually obtained 2048 points, the sampling time is 0.25s.

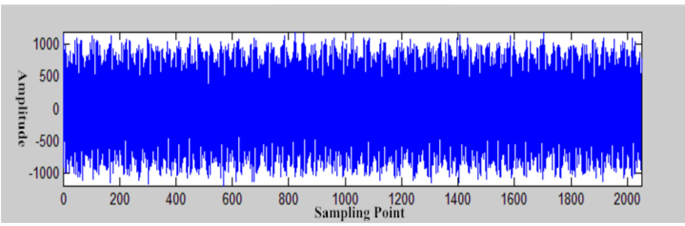


Figure 6. UM71measured signal oscillogram

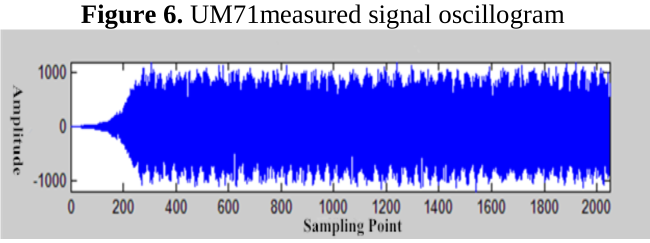


Figure 7. Signal oscillogram after filtering

First response to signal de-noising, selecting the largest flat amplitude characteristics of butterworth filter to bandpass filter, passband range 1984Hz ~ 2010Hz, maximum passband attenuation 3dB, stop-band range 1942Hz ~ 2052Hz minimum stopband attenuation of 30dB its filtered signal as shown in Figure 7. Then the filtered signal wavelet ridge extraction, to obtain the instantaneous frequency, the frequency spectrum as shown in Figure 8 which can be seen from the figure, the algorithm can be used to more accurately extract the instantaneous frequency. The number of samples due to the small amount of data, only the filter passband filter out interference outside, you cannot eliminate the influence of factors such as the trend item, so the extracted wavelet ridge error, its value is not more than 0.15% (where ε is 0.000003). When the final phase method calculating the error will increase even iteration will fail. Therefore, when using this algorithm, by adding discrimination statement automatically it can round-off and iterate failure signal point. Finally, the method of counting, to get the low-frequency square-wave signal, the waveform shown in Figure 9, the final series of processing, low frequency control signal frequencies available for 15.7842Hz, the error is only 0.0158Hz, ignore generated by Matlab operation error influence can be seen by the algorithm calculated value was close to the true value 15.8Hz, consistent track FSK signal detection resolution of at least require 0.15Hz's. Moreover, the relative error is not more than 0.5%, having met railway communications system demodulation accuracy.

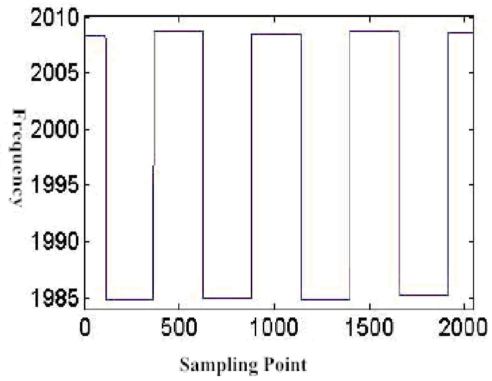


Figure 8. Instantaneous frequency plan

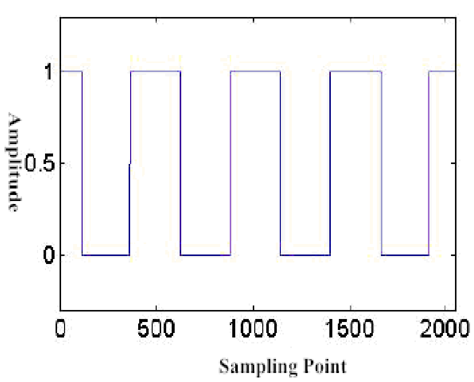


Figure 9. Low Frequency control signal oscillogram

5.2. Algorithm Verification of Second Group 0.25s Sampling Data

Similarly, make use of Matlab to import into a second set of measured data, the time-domain waveform shown in Figure 10. Above, the sampling signal is filtered, and then the filtered signal wavelet ridge extraction, to obtain instantaneous frequency, the frequency spectrum as shown in Figure 11, the final count of the use of methods to get the low-frequency square-wave signal, the waveform shown in Figure 12, and then the series of processing, low-frequency control signal to obtain a frequency of 15.7842Hz.

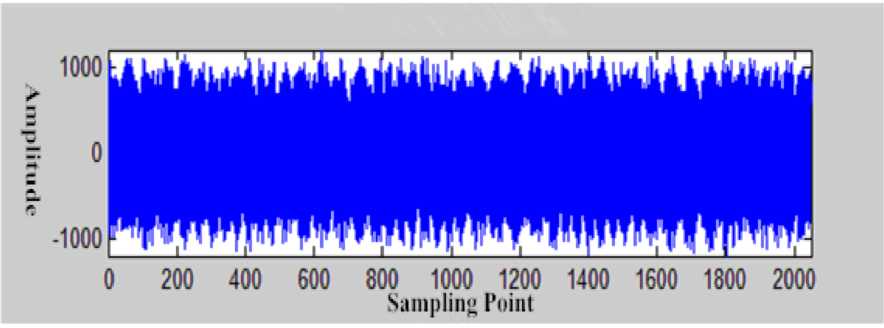
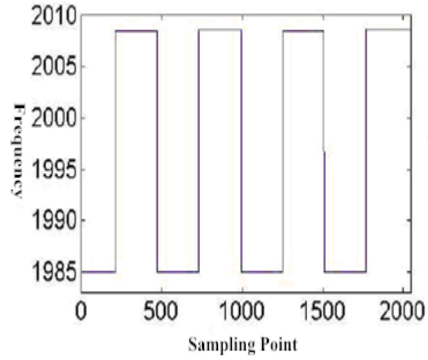


Figure 10. The second group of measured signal oscillogram



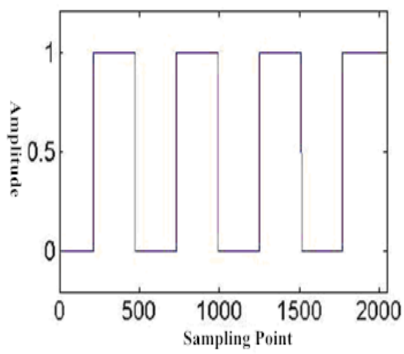


Figure 11. Instantaneous frequency plan **Figure 12.** Low Frequency control signal oscillogram

This algorithm is verified by four groups of sampling data, the resulting relative error not greater than 0.5%, to meet the accuracy requirements demodulation railway communication systems, but also in line with the track FSK signal detection resolution of at least require 0.15Hz, which fully shows demodulation method using wavelet ridge orbital parameters of the frequency shift signal is entirely feasible.

6. Conclusion

Making use of wavelet ridge to extract characteristic information of UM71 track signal, which can effectively extract the carrier signal frequencies changes and low frequency control signals of UM71 track signal, more intuitive and accurate than the existing time-domain filtering method, and low-frequency signal can be directly obtained. It cannot be obtained by time domain analysis in the past. Men respectively use computer simulation signals and the railway field measurement signal to do the validation of the algorithm. The results show that the algorithm can better determine carrier frequency and low frequency control signals of UM71 frequency shift track signal, and its detection accuracy can meet the demodulation accuracy requirements of railway communication system, thus proving the feasibility of the algorithm. This article provides a new quick and easy method for processing the FSS signals accurately and in real-time, there is a good prospect of application.

References

1. Armin Bruderlin and Lance Williams (2005) Motion signal processing, *Proceedings of SIGGRAPH 95*,p.p.97-104.
2. Michal Kraus (2004) Human motion and emotion parameterization, *Proc. of Central European Seminar on Computer Graphics (CESCG)*, Paper 42.
3. Cawkwell L, Quirke (2007) Direct multiplex amplification of DNA from formalin fixed, paraffin wax embedded tissue section, *J Clin Pathol: Mol Pathol*, 53(1), p.p.51-52.
4. Chan P K S, Chan D P C, To K-F, et al.(2011) Evaluation of extraction methods from paraffin wax embedded tissues for PCR amplification of human and viral DNA. *Clin Pathol*, 54(5), p.p.401-403.
5. Liu Wince, Zhu Dejun, Zhang Chaohong (2008) The extraction of modulation characteristics of radar signal using wavelet transform, *Proceedings of ICSP*, p.p.288-291.
6. Cornelia Gordan, Romulus Reiz (2009) Using wavelet transform for the ridges extraction of a parabolic frequency modulated signal. *IEEE DSP*, p.p.337-340.
7. B. Escudi'e and B. Tor'esanni (2010) Wavelet representation and time-scaled matched receiver for asymptotic signals. *Proc. EUSIPCOV*, p.p.305-308.
8. NAthalie Delprat (2007) Global frequency modulation laws extraction from the Gabor transform of a signal: A first study of the interacting components case. *IEEE Trans. on Speech and Audio Processing*, 5(1), p.p.64-71.
9. PH. Guillemain, R. Kronland-Martinet (2006) Characterization of acoustic signals through continuous linear time-frequency representations. *Proceedings of the IEEE(special issue on time-frequency and time-scale analysis)*, 84(4), p.p.561-585
10. Shui Li and Yingjie Yin (2012) Bearing Fault Diagnosis Based on Laplace Wavelet Transform. *TELKOMNIKA Indonesian Journal of Electrical Engineering*, 10(8), p.p.2139-2150

11. Qiang Wang, Xuemin Tian (2013) Soft Sensing Based on HilbertHuang Transform and Wavelet Support Vector Machine. *TELKOMNIKA Indonesian Journal of Electrical Engineering*, 11(7), p.p.3704-3710
12. Yingjun Sang, Yuanyuan Fan (2013) Power Quality Signal De-noising with Sub band Adaptive Algorithm. *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, 11(2), p.p.347-354