A Novel Inadvertent Modulation Signal Processing Method

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Abstract. Inadvertent modulation feature is the most valuable evidence for the identification. In order to effectively achieve the inadvertent modulation information, a signal processing method based on WMUWD is presented. Firstly, the inadvertent modulation signal model is established. Then the method of WMUWD for signal decomposition is proposed and approximate signals are fused according to mutual information for reducing unnecessary information. Simulation results show that the method is feasible to process the inadvertent modulation signal.

Introduction

As is well known that, inadvertent modulation feature is the most valuable evidence for the identification. There are always four basic character for the inadvertent modulation [1]. Since the inadvertent modulation character is contained in the signal with the normal modulation component and noises, the signal processing method is important for the information obtaining.

Common signal processing methods are the wavelet analysis algorithm, the Empirical Mode Decomposition (EMD) algorithm, the weighted fusion, the Kalman filtering [2]. However, the performances based on these conventional algorithms are not appropriate for inadvertent modulation signal processing [3-6]. Being one of the late proposed algorithms for signal preprocessing, Morphological Undecimated Wavelet Decomposition (MUWD) omits the sampling operation during the decomposition and reconstruction, which avoids the distortion [7-8].

Consequently, a method for the inadvertent modulation signal processing method based on WMUWD is proposed. In Section II, the inadvertent modulation model is established. In Section III, the novel WMUWD processing method is proposed in detail. In Section IV, we verify the method performance by simulations; In Section VI, some conclusions are put forward.

Inadvertent Modulation Signal Model

The LFM signal is shown by Eq.(1).

\[
\begin{align*}
x(t) &= A(t) \sin(2\pi f_c t + k\pi t^2 + \varphi_0), 0 \leq t \leq T \\
A(t) &= \text{rect}(t / \tau) = \begin{cases} 1, & -\tau / 2 \leq t \leq \tau / 2 \\
0, & \text{else} \end{cases}
\end{align*}
\]

where, \(\tau\) denotes the pulse width, \(f_c\) is the carrier frequency, \(\varphi_0\) is the initial phase, is the amplitude function which can be similarity equal to constant A. The phase modulation noise \(\varphi(t) = M \sin(2\pi f_c t)\) is added into Eq.(1), which is shown as Eq.(2).

\[
x(t) = A \sin(2\pi f_c t + k\pi t^2 + \varphi(t)), 0 \leq t \leq T
\]

Based on analysis, the phase noise produced by transmitter is the advertent modulation, which is the result of the combination modulation of limitless random signals. Therefore, the LFM signal model with inadvertent modulation is shown by Eq.(3).
\[ x(t) = A \sin(2\pi f_c t + k t^2) + \sum_{i=1}^{M} \left\{ \frac{M}{2} A \left[ \sin(2\pi (f_c + f_m + k t / 2)) - \sin(2\pi (f_c - f_m + k t / 2)) \right] \right\} \]  

(3)

**The Proposed WMUWD Algorithm**

Assume that the collections of \( V \) and \( W \) respectively mean the \( i \)th signal space and the \( i \)th detail space. \( T() \) denotes the morphological operator. Considering the characters of inadvertent modulation, the morphological difference operator is applied in this article. The basic operations of MUWD are shown in Eqs.(4)-(6) \(^9\).

\[ x_{ni} = \phi^i_n(x_i) = f(x_i) \bullet (i+1)g - f(x_i) \circ (i+1)g \]  

(4)

\[ y_{ni} = \omega^i_n(x_i) = id(x_i) - [f(x_i) \bullet (i+1)g - f(x_i) \circ (i+1)g] \]  

(5)

\[ \psi^i_n(x_i, \phi^i_n(x_i), \omega^i_n(x_i)) = \phi^i_n(x_i) + \omega^i_n(x_i) = id(x_i) \]  

(6)

where, \( \phi^i_n \) means the signal analysis operator. \( \omega^i_n \) means the detail analysis operator. \( \psi^i_n \) means the wavelet reconstruction and pyramid principle \(^9\). \( f(n) \) is the initial signal and \( g \) is the flat structural element. ‘\( \bullet \)’ and ‘\( \circ \)’ denote the morphological opening operation and the morphological closing operation. \((i+1)g\) means the \( i \)th swelling operation on \( g \).

The mutual accumulation is used to approximatively calculate the mutual information by Eq.(7).

\[ I(y_i) \approx \sum_{i=2}^{cum2^2/4} + \sum_{i=2}^{cum3^2/2} + \sum_{i=2}^{cum4^2/48} \]  

(7)

where, \( cum2, cum3 \) and \( cum4 \) respectively denote the 2-order, 3-order and 4-order mutual accumulation of \( y_i \). The fusion method is shown by Eq.(8).

\[
\begin{align*}
Y_{pre} & = \sum_{i=2}^{L} k_i y_i \\
k_i & = \frac{I_j}{\sum_{j=2}^{L} I_j}
\end{align*}
\]  

(8)

where, \( Y_{pre} \) denotes the rebuilt signal with inadvertent modulation information. \( k_i \) means the fusion weight.

**Simulation Analysis**

The parameters of the simulation signal after down-conversion are shown as follows. The carrier frequency is 10MHz, the bandwidth is 10MHz, the pulse width is 10 \( \mu \)s, the amplitude \( A=1 \), the initial phase is 0, the sampling frequency is 100MHz. The LFM signal with inadvertent modulation is established based on the values of \( M_i \) and \( f_m \) shown in Table.1.

| \( f_m/\text{Hz} \) | 5   | 50  | 500 | 5000 | 5e4 | 5e5 | 5e6 |
|-------------------|-----|-----|-----|------|-----|-----|-----|
| \( M_i \)         | 0.9 | 1.33| 0.28| 0.19 | 0.08| 0.02| 0.02|

Table 1. Values of modulation parameters.

In Fig.1, it is clear to see the inadvertent modulation performance in the raising part and in the middle linear modulation part, which is marked by arrows. The white noise is added in the simulation signal. Frequency domain are shown by Fig.2.
Because of the noise and useless component, the important inadvertent modulation information are hided and it is hard to be achieved any other useful information except for the usual LFM parameters.

Based on the parameters selection presented in reference [12], the WMUWD with N=6 and L=7 is applied for the signal processing. The structure element \( g_0 = [0 0 0 0 0 0] \). The signal is decomposed according to Eqs.(8)-(10). By Eq.(11), the fusion weights are \{0.453 0.0061 0.352 0.111 0.013 0.010\}. Therefore, approximate signals are fused by Eq.(12).

\[
y_{pre} = 0.453y_1 + 0.061y_2 + 0.352y_3 + 0.111y_4 + 0.013y_5 + 0.010y_6
\]

The rebuilt signal is shown by Fig.3.

Fig.3 clearly reveals the inadvertent modulation information of the, which become much easier to be achieved. It is meaningful for the target identification and precise strike.

Conclusions

A method for inadvertent modulation signal processing based on WMUWD is presented in this paper. Conclusions are put forward as follows:

1. The inadvertent modulation signal model is established.
2. Signal is decomposed by WMUWD and approximate signals are re-fused for reducing unnecessary information.
3. Simulation results show that the method is feasible and effective.
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References

[1] Bo Tian. Study on radar emitter signal inadvertent modulation [D]. Master paper of Southwest Transportation University, 2010.

[2] Jian Sun, Hongru Li, Baohua Xu. The morphological undecimated wavelet decomposition – discrete cosine transform composite spectrum fusion algorithm and its application on hydraulic pumps [J]. Measurement, 2016, 94: 794-805.

[3] Jena D.P, Sudarsan S, Panigrahi S.N. Gear fault diagnosis using active noise cancellation and adaptive wavelet transform. Measurement 2014; 47: 356-372.

[4] Shufang L, Weidong Z, Qi Y, et al. Feature extraction and recognition of ictal EEG using EMD and SVM. Computers in Biology and Medicine 2013; 43(7): 807-816.

[5] Wei C M, Blum R S. Theoretical analysis of correlation-based quality measures for weighted averaging image fusion. Information Fusion 11(2010)301-309.

[6] Rodger J A. Toward reducing failure risk in an integrated vehicle health maintenance system: A fuzzy multi-sensor data fusion Kalman filter approach for IVHMS. Expert Systems with Applications 39(2012)9821-9835.

[7] Zhang J F, Smith J S, Wu Q H. Morphological un-decimated wavelet decomposition for fault location on power transmission lines. IEEE Transactions on Circuits and Systems 53(6)(2006)1395-1402.

[8] Huang B F, Shen L, Zhou X J, et al. Fault feature extraction of rolling element bearing based on morphological undecimated wavelet decomposition. Journal of Agricultural Engineering 41(2)(2010)204-207.

[9] Jian Sun, Hongru Li, Weiguo Wang, et al. Preprocessing algorithm for vibration signals of a hydraulic pump based on WMUWD. Journal of Vibration and Shock34(21)(2015)93-99.