Research on Life Signals Detection Based on Higher Order Statistics

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Abstract

The life signals are built on harmonic mode for their low frequency, quasi-periodicity, low SNR, and the easy submerged in strong clutter noise. The method for detecting life signal based on adaptive filter and high order statistics is presented, in which neither the Gaussian supposition of the observed signal, nor a prior information about the waveform and arrival time of the observed signal is necessary. The principle of method is to separate the spectrum of input signal into many narrow frequency bands, whose Sub-band signal is followed by a short-time estimation of higher-order statistics so as to suppress Gaussian noises. Simulated results show that the method can effectively detect life signals from noise with good convergence speed and stability, and greatly improve the signal quality with respect to LMS method.

Keywords: adaptive filter, higher-order statistics, short-time estimation, signal detection

1. Introduction

Adaptive noise cancellation technology is based on noise interference, restraining it to a very large attenuation, and improving its signal-noise ratio. But it is slow in convergence and in narrow band when signal is extracted. In actual work, often have to face a lot of non-Gaussian, non-minimum phase, the cause and effect, the non-stationary with the problem. As to the nonlinear correlation signal, noise cancellation is difficult to achieve.

Higher order statistics method is the hot spot of the signal processing because of it has good inhibitory of the different kinds of noise, not only to the unknown from related additive noise, but also can restrain the colored Gaussian noise, high order circulation statistics can automatically suppress any smooth noise influence, so it plays an important role in non-Gaussian, nonlinear, not causality, non-minimum phase, non-stationary or trimmers processing.

So, this paper put forward the algorithm of life feature detection based on adaptive filter and high-order statistics, the algorithm can to deal with the noise signal, which need not assume the unknown signal with Gaussian distribution, can extract body dynamic signal. The simulation experiments show that the method need not be waiting in the signal of the prior knowledge, can extract life parameters signal drown in strong clutter noises. The conclusion of the method is feasible and effective.

2. The Higher-Order Statistics

The high-order statistics are widely used in all need to consider the non-Gaussian, non-minimum phase, colored noise, nonlinear or cycle stability of all kinds of problems. The content of the study includes the high-order statistics, the parametric high-order spectrum analysis, causal and the not causal, non-minimum phase system identification, adaptive estimation and filtering, signal reconstruction, signal detection, harmonic recovery, multiple time series analysis and the gauss signals of time and frequency analysis, array processing, cycle time series analysis and other project.

Given a set of real random variables $x_1, x_2, ..., x_n$. Their r order ($r = k_1 + k_2 + \cdots + k_n$) joint statistics defined as:
For zero mean stationary random process \( x(t) \), the corresponding two, three, four order statistics respectively as follows:

\[
c_{2x}(\tau_1) = E\left[ x(t) x(t + \tau_1) \right]
\]

\[
c_{3x}(\tau_1, \tau_2) = E\left[ x(t) x(t + \tau_1) x(t + \tau_2) \right]
\]

\[
c_{4x}(\tau_1, \tau_2, \tau_3) = E\left[ x(t) x(t + \tau_1) x(t + \tau_2) x(t + \tau_3) \right]
\]

\[
c_{4x}(\tau_1, \tau_2, \tau_3, \tau_4) = -c_{2x}(\tau_1)c_{2x}(\tau_2 - \tau_1) - c_{2x}(\tau_2)c_{2x}(\tau_3 - \tau_2)
\]

\[
c_{4x}(\tau_1, \tau_2, \tau_3, \tau_4) = -c_{2x}(\tau_1)c_{2x}(\tau_3 - \tau_2)
\]

\[
K \text{ order statistics for } c_{kx}(\tau_1, \cdots, \tau_{k-1}) \text{, for the limited long determined signal } s(t), t = 0, \cdots, N - 1, \text{ the } K \text{ order statistics as follows:}
\]

\[
s_{k}(\tau_1, \cdots, \tau_{k-1}) = \sum_{t=0}^{N-1} s(t) s(t + \tau_1) \cdots s(t + \tau_{k-1})
\]

In order to get the statistics consensus estimates, \( k_0 \) must meet the following formula:

\[
\sum_{\tau_i < \tau_{i+1}} |c_{kx}(\tau_1, \cdots, \tau_{k-1})| < \infty \quad k=1,2,\cdots,k_0
\]

\[
k_0 = 8\text{ is the need to calculate the statistics order number two times, for example, if (7) type is established, the four order statistics of mean square consensus estimate as follows:}
\]

\[
\sigma^2 = \frac{1}{N} \sum_{\tau_1, \tau_2, \tau_3, \tau_4} \left[ c_{2x}(\tau_2 - \tau_1) - c_{2x}(\tau_3 - \tau_2) \right]
\]

By (8) formula we can gain the estimate of accumulated quantity by observed sample. By above all, it is known that zero mean random process of the two, three order statistics respectively equal with its two, three order moment, but much higher levels of cumulative amount of moment and the corresponding order is not equal, the much higher order statistics can be expressed by corresponding order moment and low order moment, and vice versa. For zero mean Gaussian random process, the cumulative amount and moment has the following conclusion:

\[
c_{1x} = 0, c_{2x} = \sigma^2, c_{kx} \equiv 0
\]
\begin{equation}
\begin{cases}
0 & (k \text{ is even}) \\
1 \times 3 \times \cdots \times (k-1) \sigma^2 & (k \text{ is odd})
\end{cases}
\end{equation}

Variance for $\sigma^2$, that is the three order statistics of zero mean Gaussian process identical to zero, and only the odd high order moment equal to zero, even high order moment not identical to zero. Therefore, when the signal contains Gaussian colored noise, in theory, the high order statistics can fully suppress the effect of noise, so as to improve the signal-to-noise ratio.

3. Adaptive Filter and Higher Order Statistics Detection System

Adaptive filter and the higher order statistics [1] constitute a detection structure system as follows:

In this system, the input signal is $x(n)$, $v(n)$ is noise. $d(n) = \sum_{i=0}^{P} x(n-i) + v(n)$ is output of expectation, $w^T = [w_0, w_1, \cdots, w_P]$ is FIR filter, the length is $P+1$, $y(n) = \sum_{i=0}^{P} w_i (n) x(n-i)$ is output of adaptive filter, the $k$ order statistics of input terminal of filter as follows:

\[ c_d(\tau_1, \tau_2, \cdots, \tau_{k-1}; n) = \text{cum} \begin{bmatrix} d(n), d(n+\tau_1), \cdots, d(n+\tau_{k-1}) \end{bmatrix} \]

(11)

The mutual statistics[2] of input of filter of $d(n)$ and output of filter of $y(n)$ as follows:

\[ c_{dy}(\tau_1, \tau_2, \cdots, \tau_{k-1}; n) = \text{cum} \begin{bmatrix} y(n), d(n+\tau_1), \cdots, d(n+\tau_{k-1}) \end{bmatrix} = \sum_{i=0}^{P} w_i c_{dy}(\tau_1+i, \tau_2+i, \cdots, \tau_{k-1}+i; n) \]

(12)

The statistics error as follows:

\[ c_{e}(\tau_1, \tau_2, \cdots, \tau_{k-1}; n) = c_d(\tau_1, \tau_2, \cdots, \tau_{k-1}; n) - \sum_{i=0}^{P} w_i c_{dy}(\tau_1+i, \tau_2+i, \cdots, \tau_{k-1}+i; n) \]

(13)
The statistics domain adaptive filtering algorithm is to adjust the adaptive filter coefficient based on the error, to get the corresponding adaptive filtering algorithm through the definition of the statistics error criterion optimization. Error criterion as follows:

\[
J(n) = \sum_{i=1}^{n} \sum_{k} \sum_{t} \sum_{k} \beta^{n-i} c(t) e^{2}(t) = \sum_{i=1}^{n} \sum_{k} \sum_{t} \sum_{k} \beta^{n-i} \left| c_{d}(t, \tau_{1}, \tau_{2}, \cdots, \tau_{k-1}; t) - \right| \sum_{i=0}^{p} w(i)c_{xy}(\tau_{1} + i, \tau_{2} + i, \cdots, \tau_{k-1} + i, t) \right|^2
\]

(14)

\((\tau_{1}, \tau_{2}, \cdots, \tau_{k-1})\) is defined as k-1 dimension plane \(R^{k-1}\). \(\beta\) is defined as forgetting factor \((0 < \beta < 1)\). Choose a suitable finite field \(\Gamma \subset R^{k-1}\) in practice. The error criterion is defined in \((\tau_{1}, \tau_{2}, \cdots, \tau_{k-1}) \in \Gamma\). So \(J(n)\) as following:

\[
J(n) = \sum_{i=1}^{n} \beta^{n-i} \left[ c_{d}(t) - c_{xy}(t) w \right]^T \left[ c_{d}(t) - c_{xy}(t) w \right]
\]

(15)

4. Adaptive Filter and HOS Design Steps

First: zero mean signals processing to life parameters signal, and implement Hilbert transformation, get analytical signal:

\[
z(t) = x(t) + jH \left[ x(t) \right]
\]

(16)

Secondly: determine the scope of the frequency of the signal through calculating energy of output of filter based on error criterion, to gain three order statistics estimated value[3] for zero mean signal of the \(z_{k}(n)\), time delay for \(\tau_{1}, \tau_{2}\).

\[
\hat{C}_{3k}(\tau_{1}, \tau_{2}, k) = \left[ \frac{1}{S_{1} - S_{1} + 1} \right] \sum_{s=1}^{\infty} z_{k}(n) \hat{z}(n+\tau_{1}) \hat{z}(n+\tau_{2})
\]

(17)

\[
S_{1} = \max\{k-K, k-K-\tau_{1}, k-K-\tau_{2}\}
\]

(18)

\[
S_{2} = \min\{k+K, k+K-\tau_{1}, k+K-\tau_{2}\}
\]

(19)

\[
z_{k}(n) = \begin{cases} z(n) w(n-k), & k-K \leq n \leq k+K \\ 0, & \text{else} \end{cases}
\]

(20)

Window function, which length is \(2K + 1\), usually take \(K = 2\).

Finally: extracted of useful information of signal through high-order statistics diagonal slices[4,5], and effectively reduce the computational complexity. Adjust the adaptive filter coefficient based on the error, and then using nonlinear function test results transient signal can be given the arrival time and waveform envelope, thus completing the signal feature detection.
\[ \rho(j) = \sum_{i=0}^{\infty} \hat{c}_{ij}(0,0; j) - \hat{c}_{ij}(-1,1; j) \]  

(21)

5. Results and Analysis

In the paper the two process simulation is tested. The first, we do pretreatment and mathematical modeling of vital signs by life radar detected. The second, do process to the signal through adaptive filter and the higher order statistics detection system.

The basic task of the moving object detection is to distinguish and restrain fixed clutter and detection target echo according to the difference spectrum of target of echo and clutter in the frequency domain and time domain.

Echo signal also include clutter and the objective existence of the signal noise and so on, on the analysis of energy of these signals in the time domain and frequency domain, Radar echo signal include two kinds of clutter and a fixed object moving objects clutter.

Analysis of clutter and noise data acquisition of radar exploration 40 cm thick across the wall through launched of electromagnetic wave. Do histogram to clutter signal, figure 2 is a sampling clutter signal histogram. Figure 3 is Clutter spectrum diagram.

Figure 2. Real clutter the histogram

Clutter spectrum diagram as Figure 3.

Time domain and frequency pretreatment analysis[6] is done to the sampling signal, we can gain signal containing the high frequency noise and clutter interference based on frequency analysis. The figure 4 is the life signal time domain analysis. The figure 5 is the life signal frequency domain analysis, among them the frequency -50 Hz and frequency 50 Hz place for a strong bumps clutter signal.

Figure 4. Life signal time domain figure
In order to validate the adaptive filter and HOS algorithm is effective. The following is a sampling rate for 1000 Hz, sampling points for 8000 point of life parameters signal data after parallel filter bank and the higher order statistics system simulation diagram.

The experiment result is shown the system can completely extract signal from the noise drown, and the amplitude basic unchanged and improve signal-to-noise ratio. This show, the design idea of the parallel filter bank and the higher order statistics is completely feasible, and the de-noising effect is very satisfied. Signal detection provides a new train of thought and method for solve nonlinear time-varying online, and has some the feasibility and availability.

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References
