An Improved Generalized Adaptive Coherent Integrator Algorithm

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Abstract. GACI (Generalized Adaptive Coherent Integrator) algorithm is quite effective in detecting pulse signals. We aim to improve it further and present in this paper improved GACI algorithm, called by us IGACI algorithm. In IGACI algorithm, momentum factors, more than those in GACI algorithm, are introduced into the iteration formulas for weight coefficients. This greater introduction of momentum factors allows the utilization of more history information available in weight coefficients during impulse period, and accordingly the sinusoidal and LFM (Linear Frequency Modulated) signals to be detected can be integrated adaptively and coherently; thus, under the condition of low input SNR (signal to noise ratio), signal detection can be accomplished without requiring knowledge of a priori information or with a little knowledge of a priori information required. Both GACI and IGACI algorithms are used for detecting the LFM signals in white Gaussian noise. Simulation results confirm preliminarily that IGACI algorithm is indeed better than GACI algorithm, and show that IGACI algorithm is feasible.

Introduction

Adaptive Line Enhancer (ALE) based on the LMS algorithm is capable of detecting and tracking the sinusoidal and LFM signals in noisy environment[1,2]. However, its performance gets worse if input SNR becomes quite low. By introducing a predicted term to the iteration formulas for weight coefficients, Adaptive Coherent Integrator (ACI) algorithm can achieve a better performance than LMS algorithm[3,4]. GACI algorithm is an extension of ACI algorithm by using more history information and is better than ACI algorithm. What's more, LMS algorithm and ACI algorithm are special cases of GACI algorithm. This paper proposes an algorithm to make the GACI algorithm be a special case of it, called Improved Generalized Adaptive Coherent Integrator (IGACI) algorithm. Also, its detection performance is improved while compared with GACI algorithm.

The IGACI algorithm

Shynk and Roy[7] added more momentum factors to the iteration formulas for weight coefficients in LMS algorithm so that more history information could be used to improve the performance and that’s how GACI algorithm was developed. Inspired by this idea, we come up with an improved GACI algorithm (IGACI), which uses more momentum factors to the iteration formulas for weight coefficients, and works better than GACI. The iteration formulas for weight coefficients of IGACI can be described as:

$$\boldsymbol{V}(k+1)=\boldsymbol{P}(k)\cdot\boldsymbol{H}+2\mu e(k)\boldsymbol{X}(k) \qquad (1)$$

$$\boldsymbol{W}(k)=\boldsymbol{P}(k)\cdot\boldsymbol{B} \qquad (2)$$

where vector $\boldsymbol{B}=[b_0\ b_1\ \cdots\ b_{M-1}]^{\mathrm{T}}$ and vector $\boldsymbol{H}=[h_0\ h_1\ \cdots\ h_{M-1}]^{\mathrm{T}}$ are M-dimension parameters for IGACI algorithm. In the kth time index, $y(k)=\sum_{i=1}^{L}w_i(k)x_i(k)$ is the output signal and $d(k)$ is the signal we want, so the output error can be described as $e(k)=d(k)-y(k)$. $\boldsymbol{X}(k)=[x_1(k)\ x_2(k)\cdots x_L(k)]^{\mathrm{T}}$ is the L-dimension vector of input reference signal and $\boldsymbol{W}(k)=[w_1(k)\ w_2(k)\ \cdots\ w_L(k)]^{\mathrm{T}}$ is the

L-dimension vector of output coefficients.

$$\boldsymbol{P}(k)=[\boldsymbol{V}(k)\ \ \boldsymbol{V}(k-1)\ \ \cdots\ \ \boldsymbol{V}(k-M+1)]$$

$$=\begin{bmatrix} v_1(k) & v_1(k-1) & \cdots & v_1(k-M+1) \\ v_2(k) & v_2(k-1) & \cdots & v_2(k-M+1) \\ \cdots & \cdots & \cdots & \cdots \\ v_L(k) & v_L(k-1) & \cdots & v_L(k-M+1) \end{bmatrix}$$

is a $L\times M$ dimension matrix and μ is the step-size parameter.

Obviously, IGACI algorithm is the same as GACI algorithm when $\boldsymbol{B}=[1\ \ 0\ \ \cdots\ \ 0]^{\mathrm{T}}$.

The weight coefficients will converge to Wiener solution if the input sequence $\{\boldsymbol{X}(k)\}$ can meet the following conditions [8]:

(1) $\{\boldsymbol{X}(k)\}$ is not correlated in time, i.e., $E\{\boldsymbol{X}(k)\cdot\ \boldsymbol{X}^{\mathrm{T}}(j)\}=0$, $k\neq j$

(2) $\{\boldsymbol{X}(k)\}$ is a zero mean stationary Gaussian random sequence, and not related to $\{d(k)\}$.

Besides, the convergence constant and stability condition of the algorithm is influenced by the eigenvalue of the correlation matrix $\boldsymbol{R}_{xx}^{\mathrm{T}}$ of $X(k)$ and parameters of IGACI ,be it **H**、M、N、L、**B** etc. This tells us that if parameters are chosen appropriately, we can be sure about the convergence of the background output, which is required in signal detection. Condition (1) and (2) are no longer applicable if there exists signal in the input sequence. If so, the adaptive coherent integrator starts to work and its output will have an exponential growth while peaks when the signal ends. Then, the output will rapidly converge to a status that there's no output signal. The signal can be detected adaptively through the steps described above.

Fig.1 and Fig.2 illustrates the block diagram of GACI algorithm and IGACI algorithm respectively; Fig.3 illustrates the principle diagram of IGACI, it is similar to GACI algorithm.

Momentum factor is so important to the algorithm that its quantity determines how much history information is available to use. Generally, the performance improves with the quantitative growth of momentum factor. However, the algorithm can no longer be improved if momentum factors are large enough，because the number of momentum factors is related to correlation time:

$$|\rho_x(\hat{\tau})|=0.05 \qquad (3)$$

where $\rho_x(\tau)$ is the correlation coefficient of the signal. Correlation time $\hat{\tau}$ is the value of τ decided by $|\rho_x(\tau)|=0.05$. We consider that $\boldsymbol{X}(k+\tau)$ does not correlate with $\boldsymbol{X}(k)$ when $\tau>\hat{\tau}$. When the number of momentum factors reaches to a certain extent which makes the used history information is beyond the correlation time, the signal stops integrating. What's more, the amount of calculation and the number of parameter will increase with the increase of the number of momentum factor. Thus, momentum factor, i.e., vector **B**, should be chosen considering signal characteristics and the system requirements.

Results

Several simulations are done in the computer to verify the theoretical analysis. IGACI algorithm and GACI algorithm are used to detect the LFM signal corrupted by white Gaussian noise to compare their performance. The bandwidth of the LFM signal used in the simulation is 2 KHz and the signal duration is 50ms. Simulation Results are illustrated in Fig.4.

Fig.4 shows the comparison of detection performance between GACI algorithm and IGACI algorithm with different input SNR. We can find that IGACI algorithm has advantages in detecting signals contrast to GACI algorithm. The latter one can no longer detect the signal when the input SNR is quite low (SNR=-10dB) while the former one can robustly accomplish the detection through sacrificing its calculating speed. However, the realization of IGACI algorithm on digital signal processor is feasible at the cost of high computational complexity.

Conclusion

This paper analyzes the relations between some algorithms and proposes the Improved Generalized Adaptive Coherent Integrator (IGACI) algorithm based on these relations. Theoretical analysis and simulation results confirm that IGACI algorithm is indeed better than GACI algorithm and it could be widely used in the future.

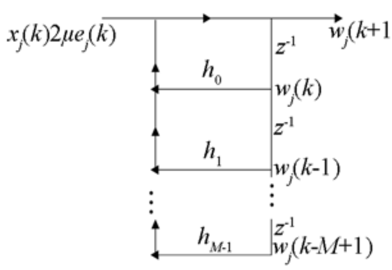


Fig.1 The *j*th block diagram of GACI

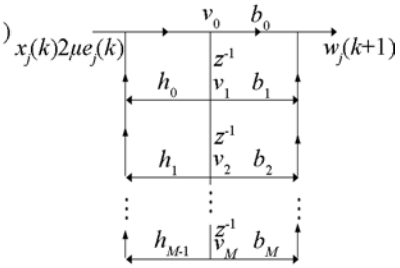


Fig.2 The *j*th block diagram of IGACI

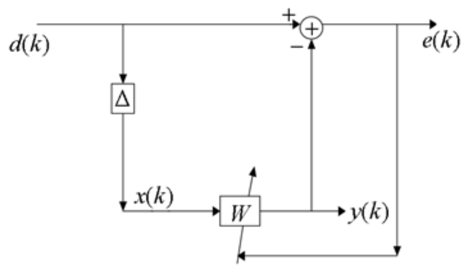
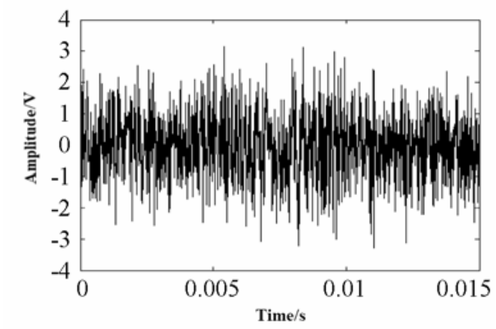
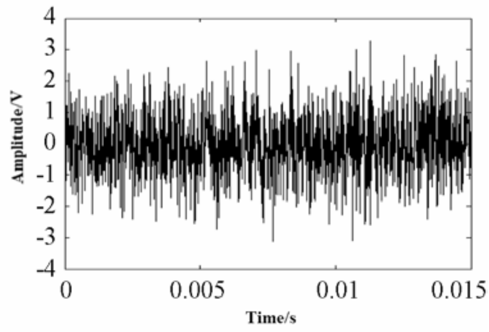


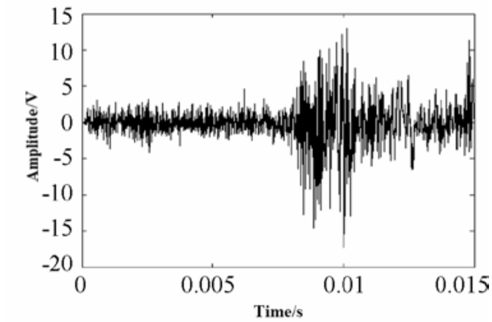
Fig.3 Principle diagram of IGACI



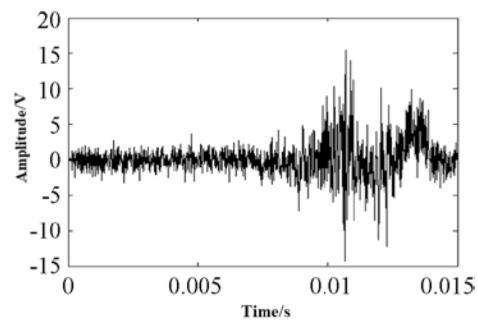
(a) Input signal(SNR = −5dB)



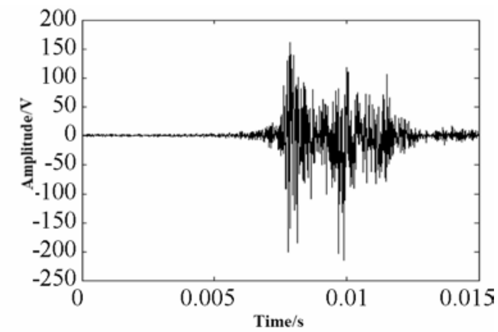
(b) Input signal(SNR = −10dB)



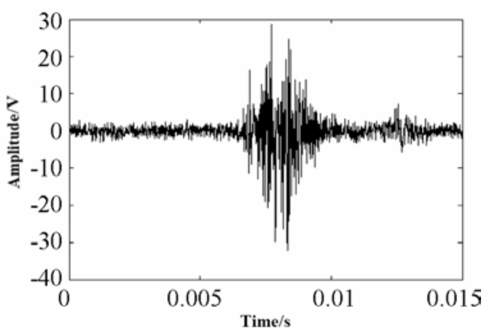
(c) Output signal based on GACI according to (a)



(d) Output signal based on GACI according to (b)



(e) Output signal based on IGACI according to (a)



(f) Output signal based on IGACI according to (b)

Fig.4 Computer simulation results

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