.Project 2: Adaptive Line Enhancer

Background

The adaptive line enhancer (ALE) is a device that may be used to detect a periodic signal buried in a broad-band signal background.

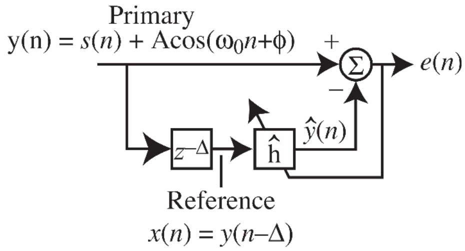

Figure: ANC (Haykin p. 386)

The ALE is in fact a degenerate form of the ANC in that its reference signal, instead of being derived separately, consists of a delayed version of the primary signal. The delay, Δ is called the prediction depth or decorrelation delay of the ALE. The reference signal to the adaptive filter is given by

$$x(n) = y(n - D)$$

and is processed to produce an error signal,

$$e(n) = y(n) - \hat{y}(n)$$

where the output of the adaptive filter, $\hat{y}(n)$ is given by

$$\hat{y}(n) = \hat{h}^T(n)\, x(n)$$

¿ $\hat{h}^T(n)\, y(n - D)$

The error signal is used in the adjustment of the *N* coefficients of the adaptive filter.

Time-Domain Analysis of ALE

Consider a primary signal, *y*(*n*) which consists of a sinusoidal component, $A_0 \cos(\omega_0 n + \phi_0)$ buried in wide-band signal of interest (SOI), *s*(*n*)

$$y(n) = s(n) + A_0 \cos(\omega_0 n + \phi_0)$$

where f_0 is an arbitrary phase shift and the signal *s*(*n*) is assumed to have zero mean and variance s_v^2. The ALE acts as a signal detector by virtue of two actions

- The prediction depth, Δ is assigned a value large enough to remove the correlation between the SOI, *s*(*n*) in the original input signal and the SOI *s*(*n* – Δ) in the reference, while a simple phase shift equal to $w_0 D$ is introduced between the sinusoidal components in these two inputs. Thus if *s*(*n*) is assumed to be uncorrelated to *s*(*n* – Δ), the adaptive filter cannot do anything about this signal in terms of minimizing the MSE, however, the adaptive filter can adjust so that the sinusoidal portion of *e*(*n*) is small.
- The adaptive filter coefficients are adjusted by the LMS (or NLMS) algorithm so as to minimize the MSE and thereby compensate for the phase shift $w_0 D$.

The net result of these two actions is the production of an output signal $\hat{y}(n)$ that consists of a scaled sinusoid in noise of zero mean. In particular, when w_0 is several multiples of π / *N* away from zero or π, it can be shown that

$$\hat{y}(n) = s_{out}(n) + aA_0 \cos(\omega_0 n + \phi_0) \tag{1}$$

where ϕ_0 denotes a phase shift, and $s_{out}(n)$ denotes an output noise. The scaling factor *a* is defined by

$$a = \frac{(N/2)SNR}{1 + (N/2)SNR}$$

where the signal-to-noise ratio (*SNR*) at the input of the ALE is given by

$$SNR = \frac{A_0{}^2}{2\sigma_s^2}.$$

According to (1), we can see that the ALE acts as a "self-tuning filter" whose frequency response exhibits a peak at the angular frequency, w_0 of the incoming sinusoid, hence the name "spectral line enhancer" or simply "line-enhancer."

Example: Suppose that our ALE has *N* = 16, $A_0 = 1$, and $s_s^2 = 1$. Then,

$$SNR = \frac{1}{2}$$

and

$$a = 4/5.$$

Therefore the error signal (output of the ALE) is given by

$$\begin{aligned} e(n) &= y(n) - \hat{y}(n) \\ &= A_0 \cos(w_0 n + f_0) + s(n) - aA_0 \cos(w_0 n + f_0) + s_{out}(n) \\ ¿&(1-a)\cos(w_0 n + f) + s(n) + s_{out}(n) \\ ¿&\frac{1}{5}\cos(w_0 n + f) + s(n) + s_{out}(n) \end{aligned}$$

We can see here that we've scaled the amplitude of the sinusoid by a factor of 1/5 or –14dB but also added an output noise $s_{out}(n)$.

Frequency-Domain (Spectral) Analysis

Due to time constraints, spectral analysis of the ALE ill not be covered in lecture. However, the complete analysis can be found in the text.

Algorithm

The algorithm can be found in Section 6.5 of the textbook.

Memory Layout

The ale.dat file is available on the EE492/EE592 web page.

