NEAR REAL-TIME ADAPTIVE RADAR PROCESSING USING ANALOG DITHERS

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ABSTRACT

This paper explores the performance of a novel analog technique for estimating the gradient of a cost function and its application to adaptive processing in radar. The technique relies on using analog sinusoidal dithers to estimate components of the gradient vector in near real-time with a latency on the order of microseconds. The advantages of this approach are that the adaptive processor can quickly adapt to nonstationary environments and the dynamic range at the input to the adaptive processor is not constrained by the limits of an analog-to-digital converter. Simulated results are shown for an adaptive sidelobe canceler in a radar configured with a main beam sum channel and auxiliary channels. Some drawbacks of the proposed technique for sidelobe cancelation include that it is suitable only for steepest descent type algorithms which have an inherently slower convergence rate, as well as the requirement to carefully account for or remove any time delays, and gain or phase imbalances in the analog dither circuitry, so as not to degrade the estimate of the gradient.

Index Terms— dither, steepest descent, sidelobe canceler, adaptive processing

1. INTRODUCTION

Consider any objective function $J(\boldsymbol{u})$ where $\boldsymbol{u}$ is an N-by-1 vector. For each component of $\boldsymbol{u}$, superimpose a sinusoidal dither of different frequency, as in

$$\boldsymbol{u}' = \boldsymbol{u} + \boldsymbol{\theta} = \boldsymbol{u} + \alpha\left[\cos(\omega_1 t), \quad \cos(\omega_2 t), \ldots, \cos(\omega_N t)\right]^T$$

where α is a small scalar. Using the Taylor series expansion of $J(\boldsymbol{u}')$ yields,

$$J(\boldsymbol{u}') = J(\boldsymbol{u}+\boldsymbol{\theta}) = J(\boldsymbol{u}) + \nabla J(\boldsymbol{u})^T \boldsymbol{\theta} + \tfrac{1}{2}\boldsymbol{\theta}^T \nabla^2 J(\boldsymbol{u})\boldsymbol{\theta} + \ldots$$

$$= J(\boldsymbol{u}) + \alpha \sum_{i=1}^{N} \left.\frac{\partial J}{\partial u_i}\right|_{\boldsymbol{u}} \cos(\omega_i t) + \ldots$$

The components of the gradient vector can be determined exactly once we multiply $J(\boldsymbol{u}')$ with $\cos(\omega_j t)$, for j = 1, 2, …, N. The result after using trigonometric identities is,

$$J(\boldsymbol{u}')\cos(\omega_j t) = J(\boldsymbol{u})\cos(\omega_j t) + \frac{\alpha}{2}\left.\frac{\partial J}{\partial u_j}\right|_{\boldsymbol{u}}$$

$$+ \frac{\alpha}{2}\left.\frac{\partial J}{\partial u_j}\right|_{\boldsymbol{u}} \cos(2\omega_j t) + \frac{\alpha}{2}\sum_{i \neq j}\left.\frac{\partial J}{\partial u_i}\right|_{\boldsymbol{u}} \cos\left(\left[\omega_i - \omega_j\right]t\right)$$

$$+ \frac{\alpha}{2}\sum_{i \neq j}\left.\frac{\partial J}{\partial u_i}\right|_{\boldsymbol{u}} \cos\left(\left[\omega_i + \omega_j\right]t\right) + H.O.T.$$

Note that the only constant term on the right hand side is the jth component of the gradient vector scaled by the factor $\alpha/2$, and can therefore be recovered exactly by low-pass filtering $J(\boldsymbol{u}')\cos(\omega_j t)$. Once the entire gradient vector is reconstructed, it can be used in a steepest descent algorithm to compute the next iteration of the control variables.

Previous work in this area includes reference [1] which originally described the dithering technique for use in a laser communication link. Reference [2] describes the implementation of a discrete-time version of the dithering technique on massively parallel processors for an adaptive beamforming application. Reference [3] describes a delay-insensitive dithering architecture and reference [4] describes the implementation of a wireless communication link using multiple dithers to adaptively control the radiation pattern at the transmitter phased array.

2. ADAPTIVE SIDELOBE CANCELLATION

A classic system design for removing jamming interference is the Coherent Sidelobe Canceler (CSLC) shown in Figure 1 with two input channels. Both input channels are assumed to be zero mean, wide sense stationary random processes. The primary channel, $y[n]$, in the case of a phased array, is the output of the beamforming network that sums together all the signals from the array elements. The auxiliary or reference channel, $x[n]$, is the signal from one designated array element, or some other auxiliary antenna, that is used to sample the spatial environment. The primary channel may also be the main beam channel of a mechanically rotating radar antenna. Typically, the gain of the auxiliary antenna is chosen to be higher than the sidelobe level of the array pattern. When a jammer is illuminating the array from some angular offset, the interference will be present in the main channel and ideally a scaled replica of the same interference will be present in the auxiliary channel.

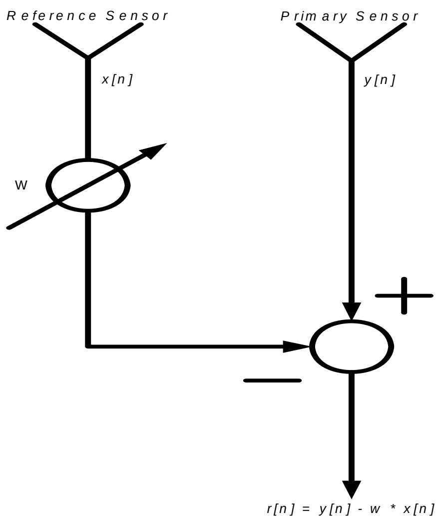

Fig. 1. Coherent Sidelobe Canceler

The output of the CSLC is a residue signal that is formed by subtracting the auxiliary channel signal, scaled by some optimum complex scalar, *w,* from the main channel signal. The objective of the CSLC is to minimize the mean square value of the array output, or $E[|r[n]|^2]$. The solution to this problem, and the optimum weight, w_*, is the Wiener solution given by,

$$w_* = \frac{E\left[x^*[n]y[n]\right]}{E\left[\left|x[n]\right|^2\right]}.$$

CSLC performance is usually measured by the cancellation ratio, defined as the output residue power divided by the input main channel power. The performance of the CSLC is best when the magnitude of the correlation between the auxiliary channel signal and the main channel signal is high. For example, if an exact replica of the interference is available in the auxiliary channel, then the CSLC will completely remove the interference from the main channel and the residue will be thermal noise. In a practical system however, there may be gain and/or phase mismatches between the auxiliary and main channels that reduce the channel correlation and thereby limit canceler performance. Also the dispersion of the incident jamming caused by traversing the width of the antenna will be present in the main channel signal but not in the auxiliary channel signal, and will further limit canceler performance.

3. SIMULATED RESULTS

It is possible to apply two independent sinusoidal dithers to the real and imaginary parts of the complex weight w to estimate the gradient of the array output power with respect to w. The frequency difference ($\omega_1 - \omega_2$) between the dithers as well as both dither frequencies ω_1 and ω_2 should be larger than the bandwidth of the low pass filter to avoid crosstalk between the dithering signals [1].

For this simulation, the dither frequencies are spaced 750 Hz apart, starting at 2750 Hz, and the scalar α was set equal to 0.2. Figure 2 illustrates the relative locations of the low pass filter (black) and dithers (blue, green) in the frequency domain.

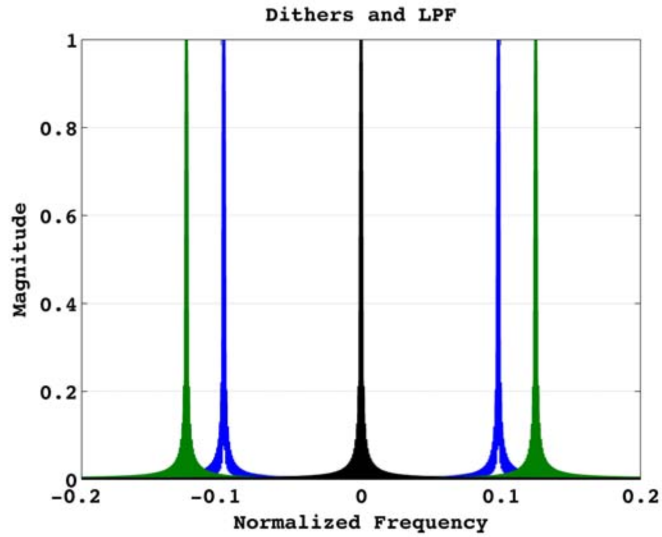

Fig. 2. Relative Locations of LPF and Dithers

The simulated data for the main and auxiliary channels was generated using MATLAB code originally developed by the authors of references [5] and [6] and generously shared with this author. This signal generation code generates the thermal noise and jamming in the main and auxiliary channels and accounts for the time delay between the two channels. The code allows the user to vary the fractional bandwidth, or the ratio of the signal bandwidth to the center frequency of the array, which is a parameter in this study. Once generated, the signals in the main and auxiliary channels are filtered by a 10-pole Butterworth filter. The filtered signals then proceed as input to the sidelobe canceler.

Figure 3 illustrates the cancellation ratio performance (red curve) of a CSLC implemented with dithers as a function of the fractional bandwidth of the interference. For this scenario, a jammer was set at 45 degrees azimuth with a jamming-to-noise power ratio of 50 dB in the main channel. The results shown are averaged over 40 Monte Carlo iterations. Also included in the figure is a blue curve showing the maximum possible cancellation ratio for a Gram-Schmidt canceler. Figure 3 shows that for narrowband interference, the CSLC with dithers achieves from 35 to 45 dB of cancellation. For wideband interference, the CSLC with dithers performs just as well as a Gram-Schmidt implementation. In this idealized simulation, extraneous time delays and imbalances in the dither channels which may further degrade CSLC performance were not accounted for.

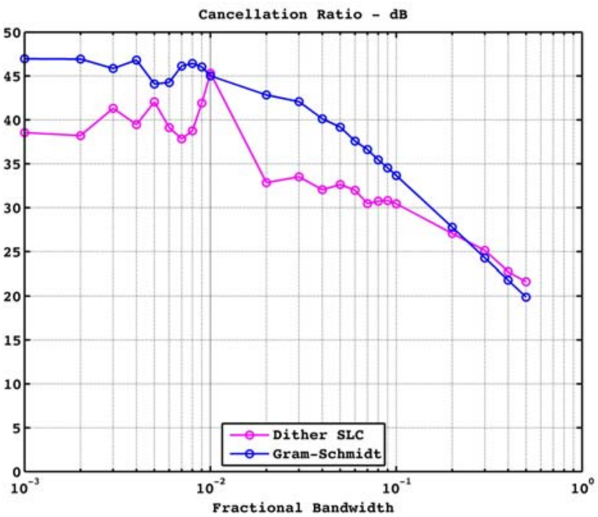

Fig. 3. CSLC Performance

4. CONCLUSION

In this paper the performance of an adaptive radar architecture based on the use of analog narrowband dithers for estimating the gradient of the array cost function is investigated. Simulated results show that this technique yields reasonable performance for a radar configured with a main beam sum channel and one auxiliary channel. This CSLC configuration is likely to be found in many mechanical rotators thereby suggesting that this class of radars is well suited for an adaptive architecture based on multiple sinusoidal dithers.

5. REFERENCES

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