AN ADAPTIVE SIDELOBE CANCELLATION ALGORITHM
FOR HIGH-GAIN ANTENNA ARRAYS

Kazunori KAMIO and Toru SATO
Department of Communications and Computer Engineering
Kyoto University
Sakyo-ku, Kyoto 606-8501, Japan
E-mail: tsato@kuee.kyoto-u.ac.jp

1   Introduction

Sidelobe cancelling is an important issue in various fields of antenna engineering. In atmospheric radar applications, where a sharp antenna beam is usually configured by a large array antenna, strong clutter echoes from surrounding mountains are the major source of interference.

Original sidelobe canceller by Howells[1] may cancel the output of the main beam under extremely strong interference signal. This effect is mitigated by adding a limiter in its feedback loop[2], but the threshold should be controlled according to the interference level. Since the sidelobe canceller is regarded as a type of adaptive antenna, Directionally Constrained Minimum Power (DCMP) algorithm[3] can be used to suppress the sidelobe echoes while maintaining the desired signal. This idea is further utilized in a variety of Generalized Sidelobe Canceling (GSC) algorithms[4, 5], which assure the response in the desired direction by controlling the weight of an output which does not contain desired signal. Efforts have been made to effectively delete the desired signal in this output by means of block filters[6, 7, 8].

Performance of these algorithms depend on the characteristics of the desired signal, and the shape of the main beam may be altered when the cancellation is not complete. The main beam pattern is an essential design factor in the atmospheric radars since the target is widely distributed in space, and the 'desired signal' is defined as the echoes which return from the main lobe region. Here we propose a new sidelobe cancelling algorithm, which extends DCMP by introducing another constraint on the weight of the receiving array so that the main beam pattern of the radar is conserved.

2   Proposed Algorithm

Received signal of a phased array is given by

$$y = W^H X \tag{1}$$

where X and W are the complex input signal vector and the weight vector, respectively. The output power is expressed in terms of the covariance matrix R_{xx} as

$$P = \frac{1}{2}[|y|^2] = \frac{1}{2}W^H X X^H W = \frac{1}{2}W^H R_{xx} W \ . \tag{2}$$

Principle of DCMP algorithm[3] is to minimize the output power under the constraint

$$W^H C = H^* \ , \tag{3}$$

where C is the desired direction vector, and H is the constraint. Here we further apply an alternate condition

$$W^H W \leq N \ , \tag{4}$$

which forces that the norm of the weight should be less than a given value N, which is set to be sufficiently lower than the main lobe level, but not to affect the weight control of the sidelobe region. This second constraint assures that the entire main lobe pattern is not affected by the weight control. Here we call this algorithm as 'DCMP Constrained Norm' (DCMP-CN) in contrast to conventional DCMP.
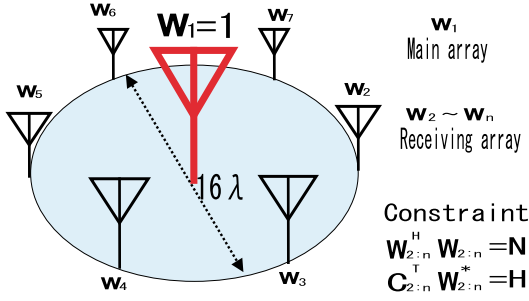
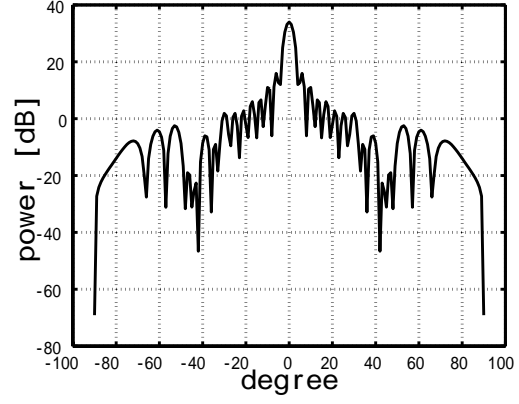Figure 1: Configuration of a high-gain antenna and the sub-array.

Figure 2: Antenna pattern of the high-gain antenna array.

The principle of DCMP-CN is thus expressed as

$$\min_{W} \left(P_{\text{out}} = \frac{1}{2} W^H R_{xx} W \right) \quad \text{subject to } C^T W^* = H \ \& \ W^H W \leq N \ . \tag{5}$$

This minimization problem with an equality constraint and an inequality condition is solved by using penalty function method. The cost function is expressed as

$$Q_k(x) = f(x) + \rho_k \left(\sum_{i=1}^{r} (g_i(x))^2 + \sum_{r+1}^{m} (g_i(x))_-^2 \right) \ , \tag{6}$$

where $f(x)$ is the function to be minimized, $g_i(x) = 0$ gives an equality constraint, and $g_i(x)_- = 0$ gives an inequality constraint. Here $(a)_- = \min\{0, a\} = (a - |a|)/2$, r is the number of equality constraints, and $(m - r)$ is the number of inequality constraints.

We choose an arbitrary increasing series $\{\rho_k\}$ of the penalty factor which vanishes to ∞. For each k, we minimize $Q_k(x)$ with a non-linear unconstrained optimization algorithm to obtain x_k starting from x_{k-1}. This procedure is iterated from x_0 by increasing the penalty factor so that x_k converges to the allowed region.

The cost function for the current case is given by

$$\begin{aligned} Q_k(W) &= \frac{1}{2} W^H R_{xx} W + \rho_k [|W^H C - H|^2 + (N - W^H W)_-^2] \\ &= \frac{1}{2} W^H R_{xx} W + \rho_k [(W^H C - H)(C^H W - H^*) + (N - W^H W)_-^2] \ . \end{aligned} \tag{7}$$

The gradient of $Q_k(W)$ in terms of the weight vector W is given by

$$\nabla_w Q_k(W) = R_{xx} W + \rho_k [2C(C^H W - H^*) - 4W(N - W^H W)_-] \ . \tag{8}$$

3 Application to High Gain Arrays

Here we consider the application of DCMP-CN to the case of a high-gain antenna array consisting of several hundred elements. In such a case, it is not practical to control all of the elements. Instead, we select several antennas at the outer edge of the array to configure a sub-array, and only control the weights of its elements as shown in Fig. 1, keeping the weight of the main array output to 1. In the radar application, the main array is used both for transmission and reception, and the sub-array is used only for reception. This configuration is useful in suppressing the clutter echoes of existing radar by adding several receiving antenna elements. In this case, the output power is rewritten as

$$P_{\text{out}} = \frac{1}{2} W^H R_{xx} W = \frac{1}{2} (x_1 x_1^* + W_{2:n}^H X_{2:n} x_1^* + x_1 X_{2:n}^H W_{2:n} + W_{2:n}^H \tilde{R}_{xx} W_{2:n}) \ , \tag{9}$$
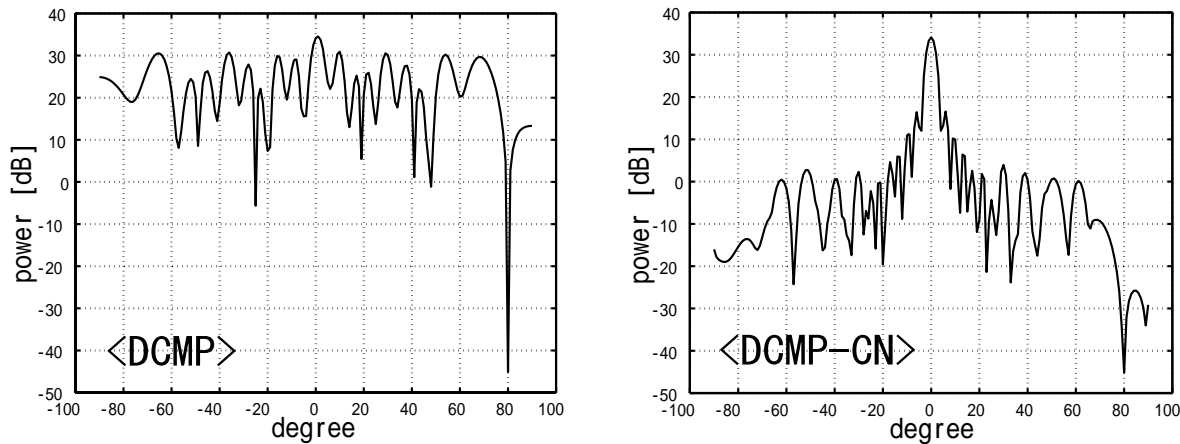
Figure 3: Antenna pattern generated by DCMP(left) and DCMP-CN(right) algorithms for SNR=20dB.

where subscript 1 denotes the output of the main array, and 2 to n correspond to sub array. Since the constraints are given only to the sub-array elements, the problem is expressed as

$$\min_{W} \left(P_{\text{out}} = \frac{1}{2}(x_1 x_1^* + W_{2:n}^H X_{2:n} x_1^* + x_1 X_{2:n}^H W_{2:n} + W_{2:n}^H \tilde{R}_{xx} W_{2:n}) \right)$$

$$\text{subject to } C_{2:n}^T W_{2:n}^* = H \ \& \ W_{2:n}^H W_{2:n} \leq N \ . \tag{10}$$

The cost function is then given by

$$\begin{aligned} Q_k(W) &= \frac{1}{2}(x_1 x_1^* + W_{2:n}^H X_{2:n} x_1^* + x_1 X_{2:n}^H W_{2:n} + W_{2:n}^H \tilde{R}_{xx} W_{2:n}) \\ &\quad + \rho_k [(W_{2:n}^H C_{2:n} - H)(C_{2:n}^H W_{2:n} - H^*) + (N - W_{2:n}^H W_{2:n})_-^2 \ . \end{aligned} \tag{11}$$

4 Comparison with DCMP

Here we compare the performance of the proposed DCMP-CN algorithm with conventional DCMP using numerical simulations. We take the MU (Middle and Upper atmosphere) radar of Kyoto University, Japan, as an example, and consider a circular array antenna consisting of 475 three-element Yagi's, whose diameter is about 16 wavelengths. Figure 2 shows a computed vertical section of the one-way power pattern of this antenna. This array is used as the main array, and four Yagi antennas used for the sub-array are arranged evenly around the outer edge of the main array. It is assumed that the desired signal comes from the vertical direction, and a strong undesired signal comes from $80°$ off the zenith. The desired and undesired signals are assumed to be uncorrelated. The background level of both arrays are set to 0 dB. The constraint level N for the sub-array is set to 0 dB in Fig. 2, which is independent from the input signals.

Figure 3 compares the pattern generated by the two algorithms. The power of the desired signal, the undesired signal, and the background level are 20 dB, 70 dB, and 0 dB, respectively. It is found that although the both algorithms suppress the undesired echo well, the antenna pattern is highly disturbed for DCMP. This is due to the high signal-to-noise ratio (SNR), which allows the algorithm to use all of its freedom in controlling the weight of the sub-array just to suppress the undesired echo, because the background noise is weak enough.

Figure 4 is same as Fig. 3, but with a much weaker desired signal of -30dB. In this situation, both algorithms work equally well, because it is necessary also for DCMP to maintain the antenna pattern in order to suppress relatively strong background noise. Comparison of Figs. 3 and 4 clearly shows that DCMP-CN always guarantee the main array pattern since the small weight of the sub-array prohibit it to disturb the main lobe region.
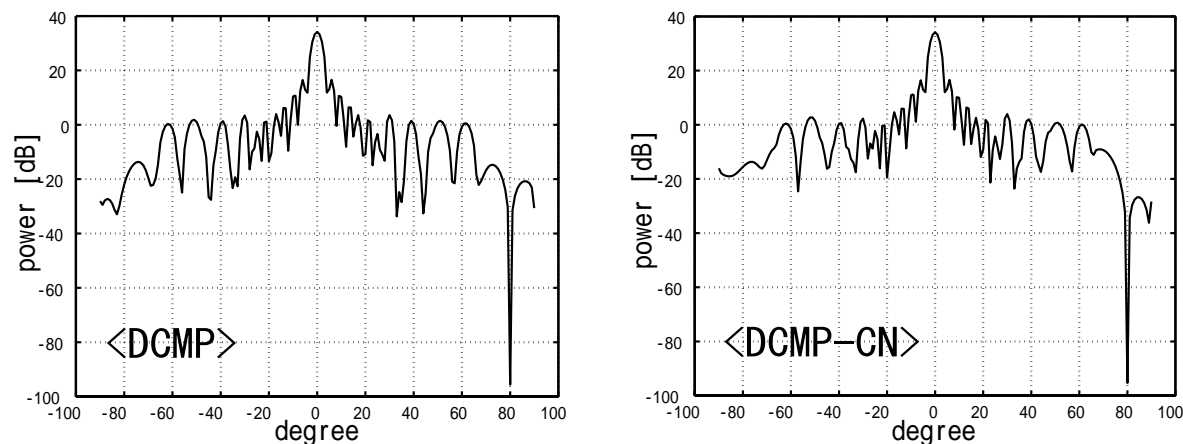
Figure 4: Same as Fig. 3, but for SNR=-30dB.

5 Summary

We have proposed a new algorithm of sidelobe cancellation for high-gain antennas. By constraining the weight norm of the sub-array as well as the response of the main antenna to the desired direction, good cancellation of undesired signal is achieved without disturbing the main beam pattern. It should be noted that the proposed algorithm does not require any knowledge on the input signal.

The proposed method can be easily implemented to existing high-gain antenna systems by adding a small number of receiving antenna elements. We will further investigate its performance under realistic conditions of atmospheric radar by using real data, and develop real time program for actual use.

We plan to implement it to the Equatorial Atmosphere Radar in Indonesia, and also to the planned atmosphere radar (PANSY) at Japanese Syowa Station in the Antarctica. The same algorithm can also be applied to different situations such as noise cancellation for high-gain microphone system.

References

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