A REAL TIME 'CLEAN' METHOD FOR SMALL LINEAR ARRAYS

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Abstract:

The CLEAN method may be effective in eliminating unwanted interferences, but, in its existing form, it is too complex to be realised in small real-time systems. This paper discusses an improved approach which allows the "cleaning" of more interferences, and also simplifies the computation process to make the method suitable for real-time applications.

1. Introduction

This paper discusses a new method of minimizing the effect of unwanted signals, which is applicable to small real-time DSP-based phased arrays using relatively low-performance processors.

Briefly, conventional adaptive algorithms involve complex computations, and therefore may not be realizable in real-time by using limited-power DSP chips in a small antenna system. We therefore propose a simpler approach based the CLEAN technique, first developed by radio astronomers more than 20 years ago, and extended to general antenna applications by Tsao and Steinberg [1]. However, their algorithm is less suitable for real-time communications systems. In addition, as the maximum number of interferences that may be removed is only about one tenth of the total number of elements in the array, it is not suitable for a small array system having less than ten elements.

This paper extends the work by Tsao and Steinberg, and shows that our modified CLEAN algorithm is capable of "cleaning" a much larger number of unwanted sources. In addition, our method requires a minimum amount of signal processing power, and therefore allows real-time operations even when implemented by relatively low-performance DSP chips.

2. Basic CLEAN Algorithm

All basic CLEAN algorithms first estimates the strength of a source, and then subtract its contribution from the array input. This is carried out for all sources, i.e. desired and interferences, usually in order of their relative strength. Finally, after all sources have been accounted for, the desired source's contribution is added back to the residual to give the CLEAN array output. Ideally, the residual power should be zero, but in practice, it is a very small fraction of the desired signal power if the CLEAN process is successful.

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In fact, due to errors in estimating the strength and direction of arrival (DOA) of each source, it is not possible to completely remove its contribution by the subtracting process mentioned above. Thus, all CLEAN algorithms requires the reiteration of the "cleaning" process mentioned above until the residual power falls below a given threshold.

3. Real-Time CLEAN For Small Array

Small arrays normally do not have a lot of processing power. Thus, for real-time operations, sophisticated adaptive algorithms may not be the best solutions. On the other hand, the CLEAN algorithm is simple, and does not involve a lot of complex computations, and therefore could be used in small real-time arrays.

However, with the CLEAN algorithm given by Tsao et al., the "cleaning" process was accomplished in a single loop, so that the errors tend to accumulate. More specifically, due to the above mentioned errors, after the attempted removal of n sources, the remaining signal will still contain the sum of the residuals from these sources, which would distort the antenna array response and hence affect the determination of the strength and DOA of the $(n+1)^{th}$ source. Consequently, it is difficult to obtain good results when the number of unwanted sources is a large fraction of the number of elements in the array.

In order to minimize the residual errors, we employ a multi-loop approach, by which the desired signal is repeatedly added back to the remaining signal for re-estimation straight after the removal of a strong interference. Because the array response is less distorted after the removal (even if incomplete) of significant interferences, the re-estimated parameters of the desired signal will be more accurate. Re-estimation of other sources may then be carried out in succession to improve the "clean" process. Because of the improved accuracy, our CLEAN algorithm can be applied for a much larger number of interference sources than possible with the technique by Tsao et al.

In addition, in order to speed up the process, we only carry out the CLEAN process periodically, taking into account the fact that the communications environment does not change significantly over a short period of time. That is, after processing the **NxN** input sample matrix to obtain the N "cleaned" outputs, we then use these known data to calculate the corresponding optimal weight vector, and then apply this vector to subsequent input samples to obtain desired outputs. After a period of time, the CLEAN process will again be carried out on the latest **NxN** input sample matrix, and the whole procedure is repeated.

In our approach, two thresholds are used to test the completion of the CLEAN process. In order to achieve real-time operations, the CLEAN time and hence the number of iterations must be limited. If this threshold is exceeded, it means that the CLEAN algorithm converges too slowly, and the result is only "partially cleaned". The second threshold is set by the CLEAN residual power relative to the desired signal power. In dB form, this threshold may be expressed as follows:

$$\text{Power}(\mathbf{x}_s) >= \text{power}(\mathbf{x}_r) + p$$

where $\mathbf{x}_s$ is the desired signal, $\mathbf{x}_r$ is the residual signal after "cleaning" is completed, and 'p' is a constant determined by the desired output signal-to-noise ratio and other system parameters. If this threshold is satisfied, it means that the interferences are satisfactorily "cleaned".

4. Results and Discussions

To demonstrate the performance of the clean technique described in this paper, we will present results of computer simulations carried out on an eight-element uniformly spaced linear array with interelement spacing equal to $\lambda / 2$.

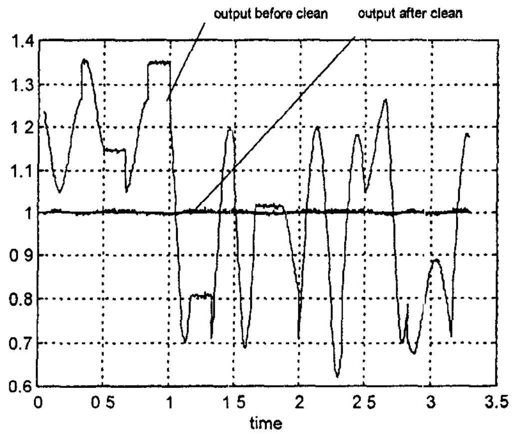
Briefly, as the antenna array consists of 8 elements, an 8x8 input sample matrix will be required for our CLEAN process to determine the optimal array weight vector. As we also assume that the signal environment does not change significantly over a short time period, we then use this set of optimal weights to process subsequent input samples to recover the desired signal from a background of noise and interferences **without carrying out the actual CLEAN process on them**. More specifically, let us consider the case where the antenna is communicating with a mobile terminal (e.g. a vehicle) in a GSM environment. As the mobile terminal signals are confined to short time bursts of 0.577 msec duration, we may assume that the optimal weights obtained from the first 8x8 input sample matrix of a given burst are also applicable to the remaining samples of that burst. This would significantly speed up the process of removing the effect of interferences.

For the computer simulation results presented in this paper, the maximum number of the CLEAN iterations is set at 20, the white noise power is -40 dB below the desired signal, which is normalised at 0dB, and the "absolute threshold" is given by

$$\text{power}(\mathbf{x}_s) >= \text{power}(\mathbf{x}_d) + 35 \text{ dB}$$

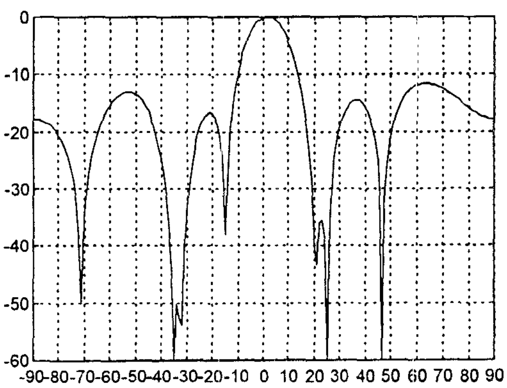
As the first example, we will consider the case where there are two directional interferences at 25° and -32° with powers of 8dB and 4.6dB, and the desired signal is at 0°. All the signals are frequency modulated with constant envelope. In this case, the "absolute" threshold is satisfied after only 8 iterations. Thus, as expected, a "highly cleaned" desired signal is obtained at the output.

Figure 1a shows the simulated output plotted as a function of time. It can be seen that, without 'cleaning', the effect of the interference is to cause the signal to fluctuate significantly in a random manner. However, after 'cleaning', the amplitude of the signal remains practically constant as required, i.e. very close to unity, the normalized value.



x-time (10^{-3} second) y-relative amplitude

Figure 1a: Array outputs of the experiment one



x- angle (degrees) y-power(dB)

Figure 1b: Array pattern using CLEAN weights

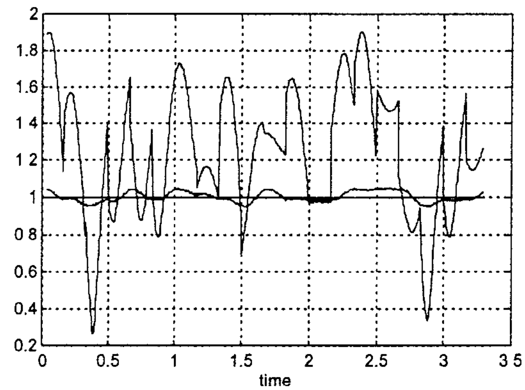
In Figure 1b, the effect of the CLEAN process is presented in a more conventional manner, where the array directional response is plotted after the CLEAN optimal weights have been applied. Clearly, two nulls below -50 dB are effectively steered to the directions of the interferences.

The second example consists of four interference sources at 32°, 27°, 67° and -59° with powers of 1.7 dB, 0.68dB, 10dB and 11dB respectively. Again, the desired source is at 0°, and all of them are frequency modulated with constant amplitude. In this case, the "clean" process stopped after 20 iterations, which means that only a "partially cleaned" output would result.

Nevertheless, as shown in Figure 2a, the output amplitude fluctuation after cleaning is still small compared to the output before "clean", and the CLEAN result is still practically acceptable. Figure 2b shows the radiation pattern after the CLEAN process. Due to the larger number of rather close interference sources, the performance is poorer in this case, and some of the nulls are off their targets by more than two degrees, but the two strong interference sources at -59°, 67° are still significantly suppressed. Better results should be expected if the array has larger number of elements.

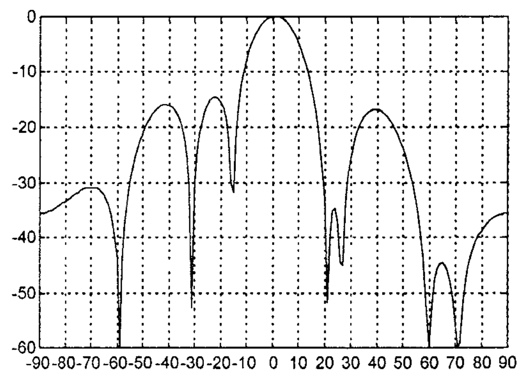
4. Conclusion

The proposed CLEAN technique is quite effective in eliminating the interferences, even when their numbers is a significant fraction of the number of the array elements. But as shown above, it does have some shortcomings, and is less successful if the interferences are too close together. In addition, like many adaptive algorithms, the CLEAN technique is very sensitive to error in estimating the DOA of the desired signal. Finally, the algorithm is fast and suitable for real time applications.



x- time(10^{-3} second) y-nomalizes amplitude

Figure 2a: Time-domain display of array outputs



x- angle(degrees) y -power (dB)

Figure 2b: Radiation pattern using CLEAN weights

Reference:

1. J. Tsao and B.D. Steinberg, "Reduction of sidelobe and speckle artifacts in microwave imaging: the CLEAN technique", IEEE trans. Antennas Propag., April, 1988, pp. 543-556.