ADAPTIVE PHASE COMPENSATION FOR DISTORTED PHASED ARRAY BY MINIMUM SIDELOBE RESPONSE CRITERIA

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ABSTRACT

Non–point sources are utilized to be the beamforming source for distorted phased array antennas. Since adaptive phase compensation is a non–linear optimization problem, an approximate solution is found to solve it. Thus the adaptive active array beamforming problem is converted to be the mostly known adaptive array beamforming problem.

INTRODUCTION

There are two possible situations to encounter distorted array. One is that the structure of a phased array antenna is non–rigid. The other is using large phased array for high resolution purpose, such as in radar imaging [1]. As the array size getting large, it is difficult to guarantee that the array elements will be located within a tolerence allowed. The major problem of distorted array is the phase errors introduced by the position errors of array elements. In general, phase errors may cause high sidelobe level, mainbeam degradation, mainbeam brodening and beam pointing error.

A well known technique to compensate the phase errors adaptively is the retrodirective beamforming. This technique was classified to be a problem of adaptive active array in [2]. The major limitation of this technique is the requirement of a point source to be used as beamforming source. In this paper, the beamforming source is assumed to be non–point sources. In real cases, such sources may be independent scatters from radar clutter or reflection from continuous extend targets. The problem of using non–point source as a beamforming source is how to deduce the phase error information by a signal processing algorithm. Since the relation between phase and signal amplitude is non–linear, such algorithm will usually be iterative, eg, the algorithm in [3]. The drawback of using an iterative algorithm is the difficulty in analyzing its performance. In this paper, a non–iterative solution is to be presented. It utilizs an a–priori knowledge about the sidelobe region of target field, which is the non–illuminated region of a radar illuminator, to find a phase vector which minimize the array response in that region. An approximate solution of this phase vector can be found by solving a standard adaptive array problem.

THE PHASE COMPENSATION ALGORITHM

For the case of array radar with pulsed waveform, the target field is illuminated by a transmitting antenna having a beamwidth of U. As shown in Fig. 1, the region of U defines the visible field of view (VFOV) of the system and can be known to the system precisely. Depending on the aperture size of array elements

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and their spacing, there is a clear region outside VFOV, which is called sidelobe region V here. Anything located in V is illuminated by the sidelobe of the transmitting antenna only, therefore it is assumed that there is no signal to be reflected from region of V.

The target field is range gated to be range bins. Let the range bin be characterized by a scene function t(u), for a linear array working in far field condition, the scatter field at the receiving array is the Fourier transform of t(u), where $u=\sin(\theta)$ and θ is the angle from broadside of the array. The scatter field sampled by an ideal array is

$$s(n) = \int_U t(u) \exp(-jkndu)\, du \;\; ; \;\; n = 1..N, \qquad \text{......(1)}$$

where k is the wavenumber, d is the array element spacing, n is the array element index and N is the total number of array elements. Let the phase error associated with the n–th array element be ϕ_n, by neglecting noise and other sampling errors, the scatter field is sampled to be $x(n) = s(n) \exp(j\phi_n)$.

The directional response of the array is the inverse Fourier transform of x(n)

$$f(u) = \sum_{n=1}^{N} x(n) \exp(jkndu) \qquad \text{......(2)}$$

In.order to compensate the phase errors in the array data, a compensation phase θ_n is introduced to each array element, then the compensated array output is

$$g(u) = \sum_{n=1}^{N} x(n) \exp(j\theta_n) \exp(jkndu) \qquad \text{......(3)}$$

$$= \sum_{n=1}^{N} s(n) \exp(j\phi_n) \exp(j\theta_n) \exp(jkndu).$$

Since there is nothing in the sidelobe region, the array output should be sidelobe response only when it is scanned inside V. However, due to the phase error, the array output in V is in general not negligible sidelobes. An algorithm can be used to minimize the array output over V by varying θ_n. It can be found from equation (3) that the array output will be negligible sidelobe response when $\theta_n + \phi_n = 0$, that is, the phase errors are exactly compensated. Assuming that multiple range–bin data are available, the phase compensation algorithm is to find a phase vector of θ_n such that the expected sidelobe response J is minimum, where

$$J = E[\, |g(u)|^2 \,]. \qquad \text{......(4)}$$

The expection is taken over all range bins and over whole space of V. Since J is a non–linear function of θ_n, finding the optimum solution of θ_n is a non–linear optimization problem. However, since J is a quadratic function of $w(n) = \exp(j\theta_n)$, it can be put into a matrix form as

$$J = E\left[\left|\sum_{n=1}^{N} y(n)w(n)\right|^2\right]$$

$$= \underline{w}^H R_{yy} \underline{w} ; \qquad .....(5)$$

where $\underline{w} = [w_1, w_2, \ldots w_N]^T$, $y(n)=x(n)\exp(jkndu)$ and R_{yy} is the autocorrelation matrix of y(n). A well known solution $\underline{w}_{opt}$ to minimize J is the eigenvector associated with the minimum eigenvalue of R_{yy}. The desired compensation phases are estimated as the arguments of $\underline{w}_{opt}$. Since θ_n is not directly used in the minimization of J, w(n) is not guaranteed to have unit norm, this solution is only an approximate solution of the non–linear optimaization problem.

COMPUTER SIMULATION

A computer simulation is presented here to show the performance of this algorithm. The simulated scenario consists of 11 radar range bins. One of the range bin has a scene of single point source, which is to be used as a test source for array point source response. The test source is located in the normal direction of the array, ie. u = 0. The other 10 range bins are general target fields to be used as beamforming source. There are 20 independent random scatters assigned in each range bin. The data are generated to have a SNR of 30 dB for each scatter. The simulated array has 12 array elements. The array element are spaced to sample the spatial signal at 1.5 Nyquist rate. The phase errors in the array data has a normal distribution with standard deviation of 1.5 radians.

The point source response of this array before and after phase compensation are shown in Fig 2. They are equivalently the images of the test source with and without phase compensation. It can be found that the image without phase compensation has very high sidelobes and the mainbeam splits to be two peaks. After applying the phase compensation technique based on the 10 range bin data, the image of the test source is a clear response of a point source. From the structure of its mainlobe and sidelobes, it can be found that this image is close to an ideal point source response of sinc( ) function. This shows taht the phase errors are compensated quite well.

REFERENCES

[1] B.D.Steinberg,"Radar Imaging from a Distorted Array: The Radio Camera Algrithm and Experiments", IEEE Trans. AP–29 Sep. 1981.

[2] R. A. Monzingo and T. W. Miller, Introduction to Adaptive Arrays. John Wiley & Sons, Inc. 1980.

[3] J. Tsao, "Phased Array Beamforming by The Parseval's Theorem," 1986 IEEE AP–S International Symposium, Phila. PA., June 10, 1986.

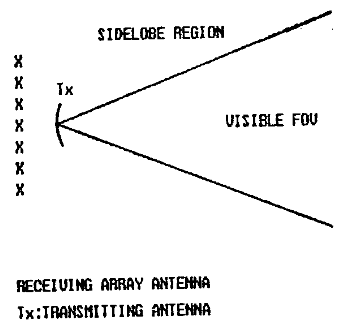

FIG. 1 GEOMETRY OF THE ARRAY ANTENNA SYSTEM

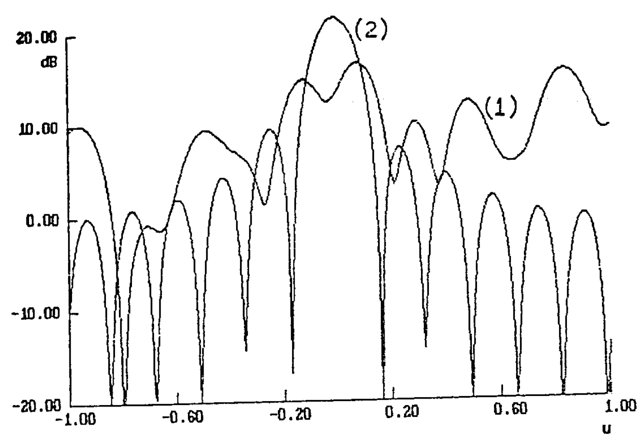

FIGURE 2 THE POINT SOURCE RESPONSE OF A 12-ELEMENT ARRAY BEFORE (1) AND AFTER (2) PHASE COMPENSATION