HIGH RESOLUTION RADAR IMAGING WITH SMALL SUBARRAYS

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ABSTRACT

Autoregressive spectrum estimation technique is applied to far field array radar imaging. Due to the superresolution capability of this technique, high resolution radar images can be made with incoherent combination of images formed by small subarrays. This solves the problem of phase calibration in large–array imaging systems. Through the increase of signal spectral response, the dectectability of target edge is improved.

INTRODUCTION

In radar imaging, the coordinates of a two–dimension image are defined as range and cross–range. The range resolution is provided by using either narrow pulse waveform or pulse compression techniques. To have a two–dimension image, the imaging system must provide an additional angular resolution in cross–range. To have a compatible angular resolution with the range resolution, a large coherent aperture is required. Such a large aperture can be synthethesized either by array of antennas or the well known SAR (Synthetic Aperture Radar) technique[1,2]. Consider a radar range cell as a one dimensional source distribution s(u) where u=sin θ and θ is the angle from the normal direction of the aperture. Assuming a far–field relationship between the target and receiver, the scatter field sampled at the n–th array element, x(n), is the Fourier transformation of s(u) as

$$x(n) = \int_U s(u) \exp(-jkndu)\, du, \quad n = 1 \ldots N,$$

where k is the wavenumber, d is the array element–spaceing, N is the total number of array elements and U is the field–of–view defined by the illumination antenna of the radar. In general, s(u) is a complex function of u and x(n) is complex also.

To obtain the image of the source function s(u), an inverse discrete Fourier transformation (IDFT) of x(n) must be formed as

$$s(u) = \sum_{n=1}^{N} x(n) \exp(jkndu)$$

The IDFT image is defined as $F(u) = |s(u)|^2$. s(u) is a coherent combination of x(n) weighted by the Fourier kernel exp(jkndu). To do the coherent combination effectively, x(n) must be sampled at the precise position nd from a reference position. Ortherwise, the phase error due to the sampling position error will degrade the image seriously. Depending on the size of total aperture Nd and the way that x(n) is sampled, the imaging system needs different techniques to compensate or

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calibrate this phase error [1,2]. In general, if aperture size is small, this position error can be controlled easily. However, for general radar imaging scenarios, an extended target such an airplane will become a point source, since small aperture can provide low–resolution image only.

In this paper, a new image formation technique is proposed. This technique assumes that the available aperture of size Nd consists of K subarrays of size Md. Each subarray is assummed to be an ideal array without position errors mentioned above. The position errors exist in the relative position of the K subarrays only. Statistical spectrum estimation technique[3] is applied on the subarray data to form a superresolution image of s(u)[4]. Then noncoherent combination of the K subarray images is followed to form a high resolution image of s(u). In general, noncoherent combination of images is not sensitive to errors in the relative position of subarrays. To make the noncoherent combination of subarray images be a proper operation, the position errors must be restricted to be a fraction of range resolution, in stead of a fraction of wavelength which is required in the coherent imaging case.

SUBARRAY IMAGING WITH AR SPECTRUM ESTIMATION

Autoregressive(AR) spectrum estimation is a well developed statistical spectrum estimation technique. Based on linear prediction theory, a discrete AR process x(n) can be put into a linear prediction structure as

$$x(n) = \sum_{i=1}^{P} a(i)\, x(n-i)$$

where a(i) i=1..P are coefficients of the order–P linear prediction filter. There are several methods to find a set of prediction coefficients which minimizes the expected prediction error $\rho = E[|x(n)-x(n)|^2]$. A specific method used here is the well known maximum entropy method (MEM) with Burg's algorithm[5]. Given a set of a(i), the all–pole spectrum is

$$P(u) = \frac{\rho}{\left| 1 + \sum_{i=1}^{P} a(i) \exp(-jkidu) \right|^2}.$$

As mentioned above, to a subarray an extended target is equivalent to a point source only, therefore linear prediction method is suitable for estimating the spectrum of subarray data. The image formed with P(u) is a sharp peak in the direction of target, it is the superresolution image of the target. Depending on the signal structure of s(u), the sharp peaks in different subarrays images will be located within the extent of a target. The high resolution image of the target is defined to be the noncoherent combination of K subarray images as

$$G(u) = \sum_{l=1}^{K} P_m(u).$$

Since $P_m(u)$ is only a point image of target, G(u) can be thought as a point–synthesized (PS) image. In terms of image formation method, this image is very different from general IDFT images. Due to limitation of space here, additional properties of this PS image will not be discussed furthermore.

EXPERIMENTAL RESULTS

A set of bistatic radar experiment data for a 200–element array is used to test this imaging technique. The target is a 2 x 5.5 m truck at a distance of 120 m. It is illuminated by a broad–beam pulsed transmitter using a wavelength of 3 cm. The array size is 28.5 m or equivalently 950 wavelengths. The range return were sampled to have a range bin size of 0.5 m. Thus the target extends over 11 range bins. There is a calibration source in the field to permit coherent imaging with the 200–element array.

The whole array is divided into 20 subarrays. Each subarray has 10 elements, which corresponds to a size of 1.4 m. The cross–range resolution of each subarray is 2.6 m. Since the width of truck (2m) is less than 2.6m, to each subarray the truck is close to a point source only. The image of truck formed by the first subarray is shown in Fig. 1. The low resolution curve is the image formed by the DFT technique. The superresolution curve is the image formed by the MEM spectrum estimation technique with an order of 5. It can be found that the target is imaged to be a sharp peak only and the peak points to a direction inside the body of target. For each range bin, there are 20 such point–images formed by 20 subarrays.

The 20 point–images were then combined incoherently to form a high resolution PS image. The resultant isometric image of the truck is shown in Fig. 2. Its dynamic range is controlled to just to show the background noise. The height of peaks is hard–limitted a little to fit the size of computer monitor. In order to check the validity of this image, the high resolution IDFT image formed by the whole 200–element array is shown in Fig. 3. It can be found that only three out of eleven range bins have strong responses. This is an intrinsic property of microwave images. Such a large–dynamic–range image has a problem of edge detection in general. Comparing with the PS image, it can be found that edge detection is not a problem in the PS image. This is because that MEM spectrum estimation can increase the sensitivity of a signal. However an accompanied disadvantage of using MEM technique is the requirement of high SNR to keep the sharp peaks be pointed to the body of target.

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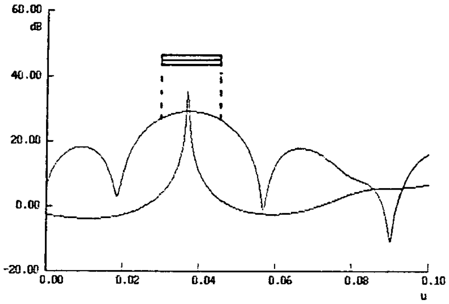

FIGURE 1 THE POINT-IMAGE OF A TRUCK FORMED BY A SUBARRAY.

FIGURE 2

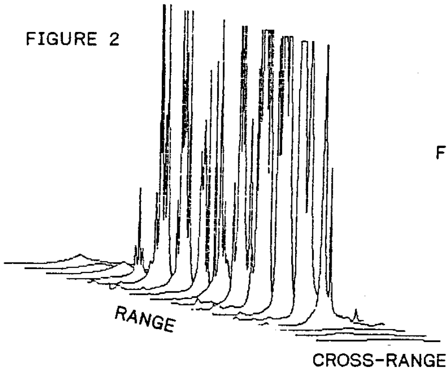

FIGURE 3

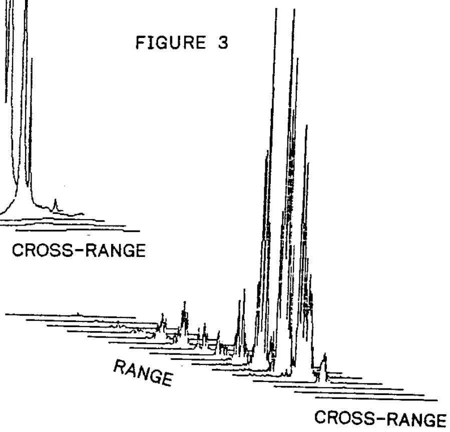

FIGURE 2 THE POINT-SYNTHESIZED IMAGE OF A TRUCK.
FIGURE 3 THE IDFT IMAGE OF A TRUCK BY THE 200-ELEMENT ARRAY.

Tuesday PM

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