Parallel ISAR Imaging of multiple targets with Airborne AESA Radar

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Abstract

The Active Electronically Scanned Array (AESA) Radar can switch beams almost instantaneously from one azimuth position to another azimuth position without scanning through the in-between region. In this paper two multiplexing schemes are proposed for parallel imaging of multiple targets taking advantage of the beam agility of AESA Radar.

Keywords: ISAR, AESA, Radar, imaging, multiple, targets, parallel

I INTRODUCTION

In recent years, the functionalities of Radar have grown in many ways like from the job of simple detection of targets to imaging the target for classification. There are also different levels of classification approaches like getting a 1-D range profile or a 2-D image of the target. Both are examples of high resolution techniques. The former method is called Range signature (RS) mode and the latter called Inverse Synthetic Aperture Radar (ISAR) mode[1][2].

The RS mode can be used for getting quick assessment of a detected target. The feature of interest may be the length of the target or position of high reflectivity points within the target. The ISAR mode is invoked when we want to examine the target in more detail like looking at the 2-D profile of the target superstructure. The principle of ISAR is based on getting the slant range details of a target by enhancing the range resolution and extracting the cross-range details from its rotational motion within the radar beam. The imaging scenario is shown in Fig-1 for radar mounted on the aircraft and imaging a ship target.

Inverse Synthetic Aperture Radar (ISAR) is the most popular imaging technique used in airborne Radar for classification of sea surface targets such as ships. The principle of ISAR is based on getting the slant range details of a target by improving the range resolution and extracting the cross-range details from its rotational motion within the radar beam. In other words, ISAR imaging basically consist of improving the resolution in range and azimuth across a target for target-classification. Slant Range resolution is improved by increasing the transmission bandwidth of the Radar. Various wideband techniques such as Stepped frequency approach, LFM Matched-Filtering approach or the Stretch processing approach are used for this[2]. For a given frequency of operation, the cross-range resolution is higher when the aspect angle change of the target during the Coherent Processing Interval (CPI) is greater [1][2]. But this has to be limited for getting a focused image since the non-linearity in rotation of target increases for large time intervals.

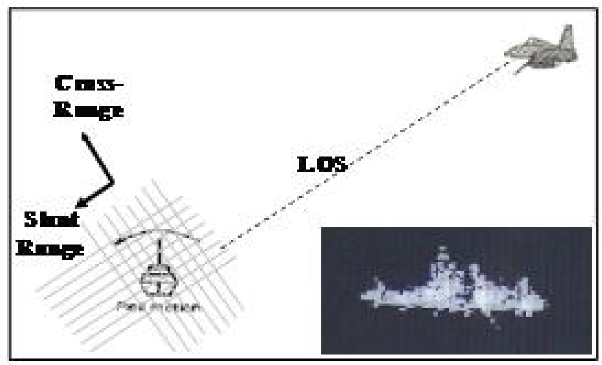

Fig. 1. ISAR Imaging Scenario and a typical ISAR image

For ISAR imaging, the Radar has to transmit a number of pulses towards the target, collect the data for that particular target and do high resolution coherent processing to get the image. If the Radar used for imaging is Mechanically Scanned Array (MSA) Radar, then it has to look at a single target till it transmits all the pulses required and receives all the echoes from the target. So if there is a need for imaging multiple targets at different ranges and angles quickly, the MSA Radar will be unable to do so.

The Active Electronically Scanned Array (AESA) Radar[3] can switch beams almost instantaneously from one azimuth position to another azimuth position without scanning through the in-between region. In this paper two multiplexing schemes are proposed for parallel imaging of multiple targets taking advantage of the beam agility of AESA Radar.

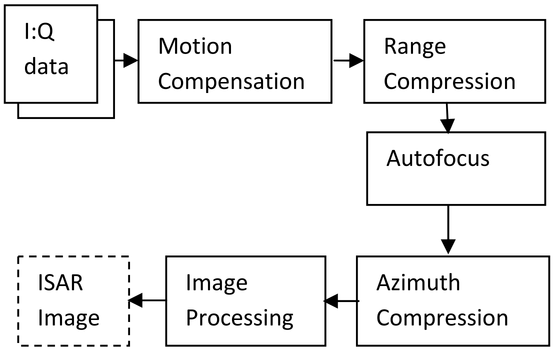

Fig. 2. ISAR Processing Chain

II ISAR PROCESSING

The signal processing blocks shown in Figure-2 constitute a typical processing chain for ISAR imaging. The first task in the processing chain is Translational Motion Compensation. It is necessary to compensate for the relative radial displacement between the Radar and the target. If not compensated, these factor lead to distortion and blurring of the image[4][5][6]. The Range compression is basically digital pulse compression by matched filtering or some other wideband technique like stretch processing. The azimuth compression block is basically a Fast Fourier Transform (FFT) operation with pre-weighing of the data. Before Azimuth Compression, the cross-range phase errors resulting from residual motion errors as well as non-uniform rotation rate of the target have to be removed through an autofocus algorithm. These are the most computationally intensive algorithms. The most widely used ones are Phase Gradient Autofocus[7] and the Mapdrift Autofocus[8].Then there is the task of image detection and enhancement before the display of final image on the Radar screen. These algorithms have already been implemented and tested on an air-borne platform and found to give satisfactory results for maritime targets imaging.

The required dwell time for ISAR imaging of a particular target depends on the angular or rotational motion of the target at that instant and the cross-range resolution required. The dwell time T is given as[1]

$$T = \frac{\lambda}{2\omega\Delta r_c}$$

Where λ is the radar signal wavelength, ω is the effective rotation rate of the target, Δr_c is the cross-range resolution. To get better resolution in the cross-range we have to process data for significantly large intervals. Typically for an X-band Radar with 1m resolution, this comes out to be around 2-4 sec. So we have to look at the target constantly for 4 seconds to get image of the target. But we process only the return from the target which may be for duration of less than a microsecond in a pulse repetition interval of 1 millisecond. So instead of waiting for the target return in each pulse we can transmit and receive multiple pulses towards multiple targets as far as the ecohos don't overlap. The beam agility of AESA Radar can be utilized for this purpose to switch the Radar beam from one azimuth location to other in microseconds. The following section explains two schemes for imaging multiple naval targets simultaneously with an AESA Radar.

III MULTIPLE ISAR IMAGING WITH AESA RADAR

One simple scheme for multiplexing the data collection process for multiple targets at different azimuth angles is shown in the Figure-3.

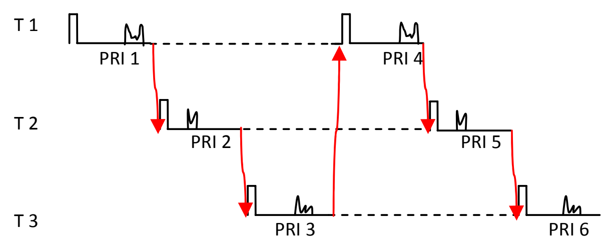

Fig. 3. PRI multiplexing scheme (The red curves represent beam switching between targets at different azimuths)

First the effective PRF required for a single target is found as follows. If the range resolution required is ΔR, then the differential frequency change for two adjacent scatterers will be

$$\Delta f = \frac{2 * \omega * \Delta R}{\lambda}$$

Dwell time required, T = 1.2 / Δf, assuming a windowing factor of 1.2.

The Doppler Bandwidth obtained for a target with height h and angular velocity ω is given by

$$\Delta fd = \frac{2 * \omega * h}{\lambda}$$

The PRF required for unambiguous sampling of this target should be greater than Δfd.

Assuming an X-band Radar with λ=0.03m, ΔR = 1m and minimum expected ω of 0.5 deg/s, Δf = 0.58 Hz.

This is the frequency resolution required for the particular scenario.

Dwell time required, T = 1.2/ $\Delta f \approx 2$ sec.

Doppler Bandwidth assuming max height of target h = 40m and taking max ω=6 deg/s

$$\Delta fd = 270 \text{ Hz}$$

So PRF can be chosen to be 300 Hz.

Number of pulses per target = T*PRF = 600

If there are 3 targets, the overall PRF = 3*300 = 900 Hz. But the pulses will be transmitted sequentially towards each target by switching the beam form one azimuth position to another azimuth position in a cyclic manner. So the pulse number 1,4,7..goes to target 1 data memory, 2,5,8…goes to target 2 data memory and 3,6,9 goes to target 3 data memory. And all the target data can be processed by different processors to produce 3 images simultaneously.

One limitation of the above scheme is that the max unambiguous range will correspond to 900 Hz and not 300 Hz. This may not be suitable in some scenarios requiring long range imaging of targets. But this limitation can be overcome by a little modification of the data collection process.

The ISAR imaging is performed for targets which are already being tracked. So the target parameters like range, angle and radial speed are already known for these targets with certain accuracy. If the targets are having ranges that are far apart, then it is possible to delink the transmission and reception of target data. First pulse is transmitted towards the target with highest range and without waiting for its return next pulse can be transmitted for the nearer target. The duration of the target return is typically in micro seconds, so there is less chance of an overlap between two target range gates. So here we are able to use a higher PRF than that needed for the farthest target. Figure-4 shows the scheme for 3 targets.

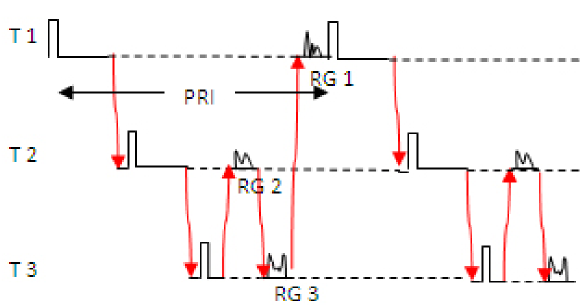

Fig. 4. Range gate multiplexing scheme (The red curves represent beam switching between targets at different azimuths)

IV CONCLUSION

In this paper we have proposed two methods for multiplexing the data collection interval of multiple targets using the beam agility feature of an AESA Radar. This will greatly help in scenarios where the operator wants to classify multiple target detections quickly.

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REFERENCES

[1] D.R. Wehner, "High-Resolution Radar" (Artech House, 1995)

[2] Walter G Carrara,et al, "Spotlight Synthetic Aperture Radar: Signal Processing Algorithms" (Artech House, 1995)

[3] Tom Jeffrey , " Phased Array Radar Design : Application Of Radar Fundamentals ", Scitech Publishing Inc,2009

[4] C.C. Chen and H.C. Andrews, "Target Motion Induced Radar Imaging"- IEEE Trans. on AES, vol. 16, No.1, pp. 2-14, January 1980

[5] J. Wang and D. Kasilingam, "Global Range Alignment for ISAR" -IEEE Trans on AES, vol. 39, No.1, pp. 351-357, January 2003

[6] D Zhu, L Wang, Y Yu, Q Tao, Z Zhu," Robust ISAR range alignment via minimizing the entropy of the average range profile", IEEE Geosci. Remote Sens. Lett. 6, 204–208 ,2009

[7] D.E. Wahl, et al, "Phase Gradient Autofocus – A Robust tool for High Resolution SAR Phase Correction," IEEE Trans. on AES, Vol. 30, No.3, pp. 827-835, 1994

[8] C.E. Mancill and J.M. Swiger, " A Mapdrift Autofocus Technique for Correcting Higher Order SAR Phase Errors," -27th Annual Tri-Service Radar Symposium Record, Monterey, CA, June 23-25, 1981, pp. 391-400

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