A Spatio-Temporal Adaptive Processing for Modeling of Seaborne Clutter

Rajeev Kr. Singh, Shams Tabrej Alam, Geetali Chakraborty, Sudarshan Chakravorty

Abstract*— The *presence of clutter is a big obstacle for proper detection of targets in seaborne radar systems. Spatio- temporal adaptive processing (STAP) helps to remove the problem of clutter by exploiting Doppler spread. The modeling requirements of clutter for spatio-temporal adaptive processing are considered in this study. Modeling of the internal motion of seaborne clutter and its effect in the clutter domain is also studied.

Keywords*— *Adaptive processing, Doppler spread, Intrinsic clutter motion,* Seaborne clutter, *Spatio-temporal.

I. INTRODUCTION

Sea clutter returns in sea-borne radar applications are spread in Doppler because of platform motion. This clearly indicates that the detection of target should be done against a strong clutter background in sea-borne radar applications. Spatio-temporal adaptive processing techniques can be used to suppress clutter and improve the detection of target by implementing an adaptive filtering approach [1, 2]. Seaborne radars also like to use phased array technology, which provides the spatial channels needed to implement spatio-temporal adaptive processing. A conventionally scanned mechanical system can be used to implement STAP in a limited way by separating sum and difference beam outputs. In order to effectively implement clutter modeling, the availability of a realistic clutter simulation tool reduces the need of data gathering. This paper aims to develop a clutter model that will be necessary for STAP implementation, based on bistatic radar geometries and internal motion of clutter.

II. STAP AND ANGLE-DOPPLER RELATIONSHIPS

STAP removes the problem of target detection in the presence of clutter by exploiting the relationship between the angular location and Doppler frequency of scatterers.

In a situation with stationary clutters, the Doppler frequency of a scattered signal resulting from ship motion becomes a single valued function of angular location relative to the scatterer. With two spatial dimensions (elevation and azimuth) and one Doppler dimension, the clutter domain forms a two-dimensional surface in three-dimensional space. Here STAP can be used to suppress the clutter and improve the probability of detection of the target by generating an adaptive space-time filter.

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The angle –Doppler relationships for ideal clutter are considered here for a bistatic radar geometry .The monostatic equation can be easily derived by co-locating the transmitter and the receiver. General bistatic radar geometry is shown in Fig.1.

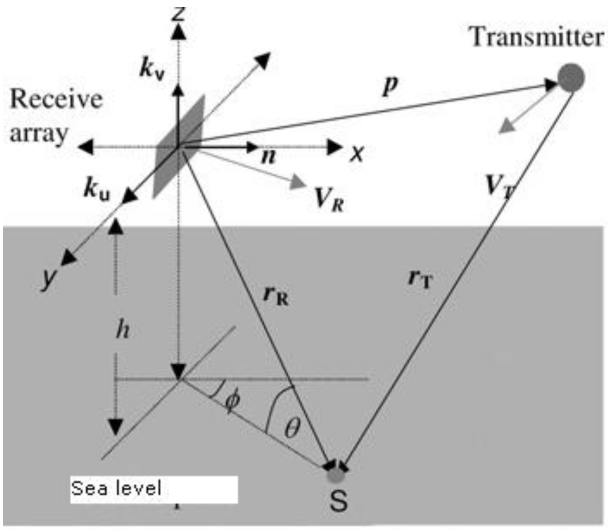

Fig.1: Bistatic radar geometry for sea clutter.

The spatial co-ordinates of the scatterer are defined relative to the receive antenna. For a planner receiving antenna with (λ /2) spacing, the normalized spatial frequencies (unambiguous range) are given by,

f_u=u/2= (cosθsinΦ)/2 and f_c=v/2= (sinθ)/2 (1),

Where "u" and "v" are the directional cosines in the azimuthal (Φ) and elevation (Θ) directions. The x-axis is considered here to be normal to the receiving antenna. The normalized Doppler frequency for a stationary scatterer is given by,

$f_D=T/\lambda[(V_T r_R/|r_R-P|)-(V_T P/|r_R-P|)+(V_R r_R/|r_R|)]$ (2)

Where λ is the wavelength, T is the pulse repetition interval (PRI), V_T and Vr are the velocity vectors of the transmitter and receiver, r_R is the position vector of the scatterer relative to the receiver and P is the position vector of the transmitter relative to the receiver. It follows that large changes in Doppler frequency over a small change of angular location can occur. In a monostatic application (p=0), the Doppler frequency depends only upon the direction of the scatterer. All these aspects are discussed in detail in [3].

III. CLUTTER MODELING AND IMPLEMENTATION OF STAP REQUIREMENT

The above model satisfies the requirement for spatio-temporal channels by generating an output for each element of a phased array.

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The element level data can then be combined into one or multiple sub –array configurations. Alternately, sub array level o/p can be formed by modeling each sub-array as a single element located at the center of the beam pattern. Overlapping sub arrays and spatial channels corresponding to full array o/p can also be modeled. Temporal channels can also be formed similarly.

A long established method to model sea clutter is to split the sea level into a number of individual cells with adequate separation to satisfy resolution requirements. Each individual cell is modeled as a point scatterer and the outputs of all the individual cells are combined to obtain the clutter returns [2, 4-6].This approach has limitations, because the sea –level always does not behave as a point scatterer. When considering pulse-Doppler radar, clutter can be modeled where each cell can be assigned a Doppler radar, clutter can be modeled where each cell can be assigned a Doppler frequency and the cell outputs are combined to form a range –Doppler map [5, 6].But this approach is again not fully compatible with STAP.

The model which is being discussed can be achieved by modeling the sea –level as a large-number of point scatterers and employing a model for the return from each scatterer [7].Doppler frequency for each cell is not directly assigned. The time delay between transmission and reception of the scattered signal is used to determine the return for a cell at each sample time. This allows variation of Doppler frequency over a wide-band and its effects can be modeled. The model splits the sea-level into range and azimuth, where resolution cells are assigned. Resolution requirements in Doppler frequency and angle subtended at each antenna between the neighboring cells are specified. Individual resolution cells are subdivided if the resolution requirements for angle and Doppler are violated. Each resolution cell is assigned a point scatterer.

The equation is used to determine the received signal from a scatterer at a particular receive element at time t_R as:-

$$S(t_R) = (PG\sigma A_e/ (4\pi r_T^2)*(4\pi r_R^2))^{1/2} *[\exp(iX)f(t_T)] \quad .. \quad (3)$$

where P is the transmitted power, G is the gain of the transmit antenna in the scatterer direction, σ is the radar cross-section value of the patch of ground corresponding to the scatterer, A_e is the effective aperture area of the receive element, X is a phase shift caused by the scattering, r_T is the range of the scatterer relative to the transmitter, r_R is the range relative to the receiver and f (t_T) is the instantaneous value of the transmitted signal waveform which is scattered, with t_T being the transmit time corresponding to the signal received from the scatterer at time t_R. In a bistatic application, this transmit time is determined from the following equation

$$t_T = t_R – [2(r_{TR} + r_{RR}) / c] – [(v_T r_{TR} + v_T r_{RR} + v_R r_{RR}) / c^2]– [r_{e1}(1 + (v_T + v_R)/c)] / c \quad (4)$$

where v_R and v_T are the components of velocity towards the scatterer of the receive and transmit antenna, respectively, r_{TR} and r_{RR} are the distances to the scatterer at the receive time from the transmitter and receiver, respectively, and r_{e1} is the difference between the distance from the scatterer to the element and from the scatterer to the center of the receive array. any changes occurring to v_R and v_T due to transverse velocity components are assumed to be negligible. The equivalent equation for monostatic application can be found by setting $v_T = v_R$ and $r_{TR} = r_{RR}$.

The model was used to generate clutter for a bistatic case involving a 32 element linear array with λ /2 spacing and a -40dB Dolph-Chebyshev window. The antenna normal was perpendicular to the direction of motion (facing sideways) and the array was electronically steered 45° forwards in azimuth. The platform is moving in straight with speed of 10m/s with a height of 50meters.The frequency was 2 GHz, the PRF was 5 KHz and the compressed pulse width was 1μs with a bandwidth of 1MHz.The clutter Doppler spectrum due to clutter motion is shown in Fig.2.

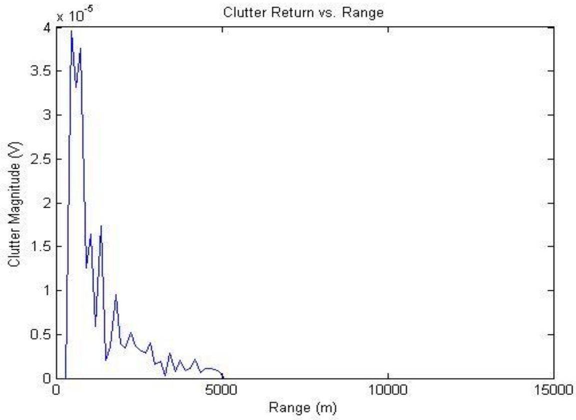

Fig.2: Clutter Doppler spectrum vs. clutter motion.

The main lobe and the side lobe clutter is clearly visible in the doppler frequency vs. the shape of the clutter doppler spectrum due to intrinsic clutter motion is shown in Fig.3.

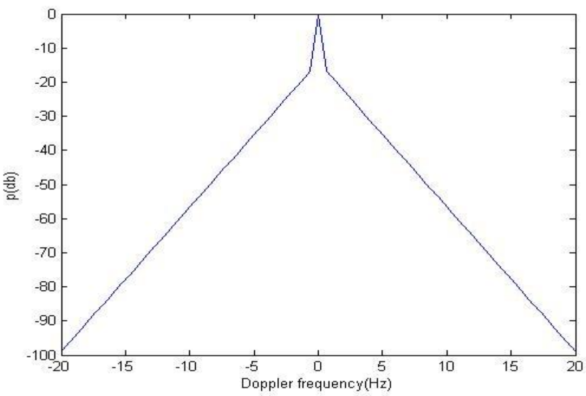

Fig.3: Doppler frequency vs. shape of the clutter.

Here P (dB) indicates the shape of the clutter Doppler spectrum due to intrinsic clutter motion.

Intrinsic clutter motion (ICM) arises when strong wind blows across the sea [8]. The radar cross-section verses range in the face of intrinsic clutter motion is shown in Fig.4.

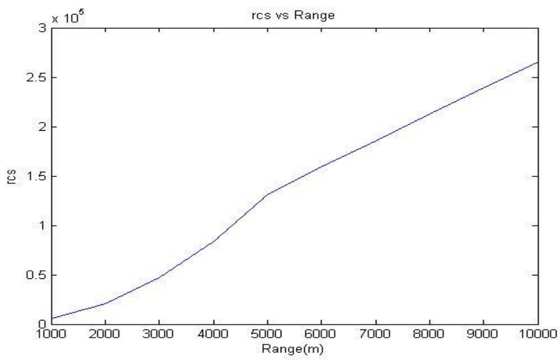

Fig.4: RCS vs. range in the face of intrinsic clutter motion.

The depression angle vs. clutter patch is shown in Fig5.

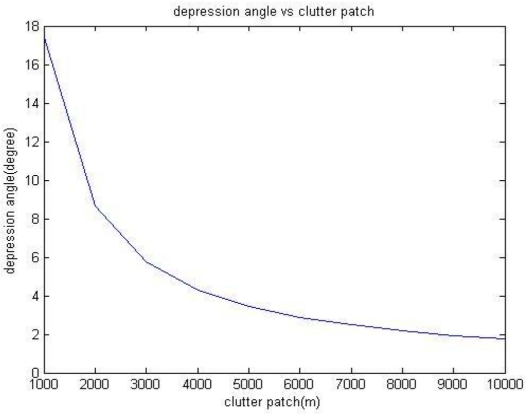

Fig.5: Depression angle vs. clutter patch.

IV. CONCLUSION

The developments of a clutter model for compatibility with STAP have been considered. Modeling of bi-static clutter and homogeneous clutter has been described. The STAP response has been shown to be consistent with the results found.

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