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STAP- A Clutter Suppression Technique in Radar Systems

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Abstract : *Space-time adaptive processing (STAP) is a signal processing technique most commonly used in radar systems. It involves adaptive array processing algorithms to aid target detection. Radar signal processing uses STAP in areas where interference is a problem (i.e. ground clutter, jamming, etc.). In Space-time adaptive processing the primary aim of the processor is to remove the effects of clutters, jammers etc. from the received signal and to make the signal useful. For this purpose filters are used. There are different methods for filtering out the unwanted signals from received signal. In this paper different approaches to STAP depending upon various factors like strength of the received signal, application area, computational easiness, etc. are explained in detail. The performance of different algorithms are compared and analyzed based on complexity, detection of signal, degrees of freedom etc. Once an algorithm is selected according to our needs, then a processor can be developed using this and many processors can be combined and embedded in the system to make the whole process object detection easier.*

Keywords -*STAP***,** *Clutter Suppression, Clutter Subspace, Jammer Subspace, Subspace Projection*

1. INTRODUCTION

Space-time adaptive processing (STAP) is a popular radar signalprocessing technique to detect slow-moving targets in the presence of a strong interference background. The spacedimension arises from the use of an array of N antennaelements and the time dimension from the use of a coherent train of M pulses. The power of STAP comes from the jointprocessing along the space and time dimensions.The data collected by STAP radars are a sequence of$N \times M$ arrays, one at each range. These arrays are typically treated as $NM \times 1$ vectors. These arrays or vectors arecalled 'snapshots.' The calculation of the optimumprocessor generally involves the inversion of the'interference + noise (I + N)' covariance matrix of eachsnapshot. This matrix is generally estimated usingsnapshots at neighboring ranges. A general assumption is that the snapshots used forestimation are statistically independent, have identical probability density functions (PDF) and obey a Gaussian distribution. A very important, practical issue in fielding a STAP-based system concerns accurately estimating the interference covariance matrix and then computing an improved adaptive weight vector. For an optimum system large sample support is required. Generally the interference will be homogenous or non homogenous or a mixture of two.

The homogenous data will independent identically distributed (IID). Mostly it will be non homogenous, which is the practical case, and the secondary data will not be IID and this will make the estimation of covariance matrix difficult. There are different approaches for STAP depending upon the interference is homogenous or non homogenous.The various approaches to STAP are discussed in detail and performance of each method has been studied.

2. STAP BACKGROUND

2.1Space Time Adaptive Processing

STAP involves two processing steps,that is spatial filtering and Doppler filtering.To sum all signals arriving at the elements of a phased array coherently, the time delay of the signal received at the antenna element at position r=(x,y,z) has to be considered.

Now consider a radar transmitting a train of Mcoherent pulses. To sum all signals arriving at the radar coherently, the phase change due to the Doppler frequency of the signal received at time T has to be compensated. Denoting the Doppler frequency of the received signal by f_D , the signal received at time T can be written as X

$$S(t, f_D) = b.e^{j2\pi ft}.e^{(-j2\pi f_D(T+t))} \approx be^{j2\pi ft}.e^{-j2\pi f_D T} \quad (1)$$

For phased array radar transmitting a train of M coherent pulses, the beam forming and Doppler filtering operation can be combined into a space-time filtering operation
$S(t, u-u_0, f_D-f_0) = a^H (u_0 , f_0) s(t, u f_D)$

If the interference situation (clutter, jamming, noise) is known, the optimum space-time adaptive filter vector w should be determined such that the probability of detection is maximized if the weight vector w is chosen so that it maximizes the signal-to-noise-plus-interference ratio (SNIR) for a given signal s0 = (u,f0) .

$$SINR = \frac{| \, w^H s_0 | ^2}{E\{| \, w^H (c + j + n)| ^2\}}$$

$$= \frac{w^H s_0 s_0{}^H w}{w^H Q w} \qquad (2)$$

The solution of this optimization is

$w = \mu Q\text{-}1 \, s (u_0 , f_0)$

where Q ={ (c+j+n)(c+j+n)H}
is the space-time clutter-plus-jamming-plus-noise covariance matrix, and μ is a normalization constant which can be chosen arbitrarily.

2.2Radar Data Cube

The radar consists of an antenna array, where each element hasits own independent receiver channel. The linear antenna arrayhas N elements uniformly spaced by a distance. The radartransmits a coherent burst of M pulses at a constant pulse-repetitionfrequency. The pulse-repetition interval is the inverse of thepulse-repetition frequency. A pulsed waveform of a finite duration(and approximately finite bandwidth) is transmitted. Onreceiver, matched filtering is done where the receiver bandwidthis equal to the transmit bandwidth. Matched filtering is carriedout separately on each pulse return after which the signals aredigitized and stored. So for each pulse-repetition interval, Rtime samples are collected to cover the desired range interval.Hence, we term R as the number of range cells.

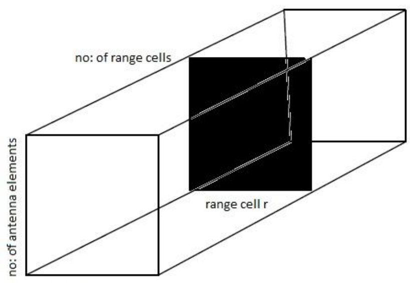

Figure 1: Radar Data Cube

Therefore withM pulses and N antenna elements, each having its own independentreceiver channel, the received data for a coherentprocessing interval consists of RMN complex base-band samples.These samples are often referred to as the data cube as shown in figure 1 consistingof $R \times M \times N$ complex baseband samples of the received pulses. The data cube then represents the voltages definedbyV(m;n;r) for m=1,2….M; n=1,2,…..Nand r=1,2,….R.These measured voltages contain the signal ofinterest (SOI), jammers, and clutter including thermal noise. Aspace–time snapshot then is referred to as samples for afixed-range gate value of r.

3. VARIOUS APPROACHES TO STAP

3.1 Conventional Matrix Inversion Approach

The interference which is the total of clutter and noise will be homogenous if it is distributed uniformly with common probability density function. The clutter described in a homogenous environment is assumed to be

Gaussian in nature i.e., the received amplitude of the clutter amplitude at an angle ψ is assumed to be Gaussian. It should also be independent and identically distributed. When we consider two distinct range bins ,the corresponding echoes will travel through slightly different media and reflected by different clutter patches. Therefore they are considered to be independent.

The homogenous clutter suppression is based on the statistical estimation of the interference covariance matrix.Conventional STAP generallyutilizes statistical methodologies based on estimating a covariancematrix of the interference using data from secondary range cells.

3.2 Displaced Phase Centre Antenna Algorithm (DPCA)

The actual research started for DPCA based STAP started in 1970's. The DPCA stands for displaced phase centre antenna algorithm. In this the effective radiation centre of the antenna is shifted backward when the platform is moving forward. Then for a few pulse intervals antenna appears to be stationary. Then for removing the clutter we such can subtract two consecutive pulses and if the clutter is uniform it will be removed. Some additional hardware is required such as a special RF modulator is built to add the difference signal to the sum signal as the antenna is rotated.

For a moving target approaching the aircraft, competing ground clutter arrives from an azimuth forward of the target angle. Proper phase adjustment between two side looking arrays is required for maintaining a null at the angle of clutter. This is accomplished by putting a time delay in the forward antenna line. The time delay is equal to the time it takes for the aircraft to traverse the distance equal to the spacing of two antennas. DPCA technique uses this time delay for the process.

3.3 Eigen Analysis Based Technique – Eigen Canceller

The aim of Eigen analysis method is to make determinations on the Eigen Structure of the space time covariance matrix.The Eigen analysis of the space time covariance matrix shows that some large Eigen values and a large number of small Eigen values are there. The no: of large Eigen values where the system energy is concentrated is given as ,

$r = 1+2BT$,

where r is the no: of large Eigen values, B is the bandwidth and T is the total duration of those signals across the array structure.

Consider a simple linear space array. The n^{th}element output due to single source at angle φ ,

$x_n = e^{j\pi \frac{\sin\phi}{2}(n-1)}$

the signal may be regarded as samples of a sine wave of frequency $\frac{\sin\phi}{2}$

The bandwidth is zero as we are considering the case of predicting one Eigen value. If the highest space time component is,

$x_{nk} = e^{j2\pi\left(\frac{1}{2}\right)(n-1)} . e^{j2\pi\left(\frac{1}{2}\right)(k-1)}$

the no: of samples required to represent the signal is N+K-2 , and lower bound is r-1.

i.e., $N+K-2 \geq r-1$

$N+K-1 \geq r$

where N is the no: antenna elements , K is the no: of pulses and r is the no: of significant Eigen values, $r \leq N + K-1$

The total power of jammer + clutter signals is given by ,

$P = \sum_{i=1}^{N} \lambda_i$

where$\lambda_i \rightarrow$Eigen values of M

3.4 Direct Data Domain(D^3) Least Square STAP

The direct data domain least square method is a deterministic method ,that means it is a non statistical method where the weight vectors are found out deterministically. This method is usually used for eliminating non-homogenous clutters. This can be applied to antenna arrays of type linear as well as circular.

D^3Based on the Solution of an Eigen value Equation

From the radar data cube we select a range cell rand consider the space–time snapshot for thisrange cell r. Let S(p;q) be the complex voltage received

Attheqth antenna element corresponding to the pth time interval for the range cell r.

$$S(p;q) = \exp\{ j(\tfrac{2\pi\Delta q}{\lambda}\cos\theta_s + \tfrac{2\pi f_d p}{f_r}) \} \quad (3)$$

where λ = wavelength of the RF radar signal,f_r=pulse repetition frequency, θ_s=azimuth angle corresponding to Doppler frequency f_d .let X(p;q) be the actual measured complex voltages that are in the data cube for the range cell r.

$X(p;q) = \propto \exp\{ j(\frac{2\pi\Delta q}{\lambda}\cos\theta_s + \frac{2\pi f_d p}{f_r}) \}$
+ Clutter + jammer + noise (4)
= V(p; q; r)

The difference signal is formed using these equations.

$X(p;q) - (\propto S(p;q)$=undesiredsignals (5)

In D^3 adaptive processing , the goal is to take a weighted sum of these matrix elements defined in equation (3.4.3) and extract the SOI ,which is going to be ∝ in the range cell r. The total no: of degrees of freedom then represents the no: of weights and this is the product N_aN_t, where $N_a$is the no: of spatial DOFs and $N_t$is the no: of temporal DOFs.

Consider the two following matrices C1and C2. The elements of C1and C2 are formed by,

C1(x;y) = S(g+h-1;d+e-1)
C2(x;y) = X(g+h-1;d+e-1)
Where
$1\leq x = g + (d-1) * N_t$
$1\leq y = h + (e-1)N_t \leq NaNt$
$1\leq d \leq N - N_a$
$1\leq e \leq N_a$
$1\leq g \leq M - N_t$
$1\leq h \leq N_t$
so that $1\leq x,y \leq NaNt$
Now, if we consider the matrix of order NaNt
$[C_2]_{N_aN_t\times N_aN_t} - \propto [C_1]_{N_aN_t\times N_aN_t}$

Then this represents the contribution of unwanted signals as the desired components have been cancelled out. Now in the STAP processing, the elements of the weight vector are chosen in such a way that the contribution from the jammers, clutter, and thermal noise is zero. Hence, if we definethe generalized Eigenvalue problem

$[R][W] = \{[C2] - \propto [C1]\}[W] = 0$

then ,∝the strength of the signal is a generalized Eigenvalue and the weights are given by the corresponding generalized eigenvector.

The total output noise power then can be obtained as

$N_{power}= \{[C2] - \propto [C1]\}H[W]H\{[C2] - \propto [C1]\}[W]$

Our objective is to set the noise power as small as possible by selecting [W] for a fixed signal ∝. This is done by differentiating the real quantity N_{power} with respect to the elements of [W] and setting each component equation to zero.

3.5 Knowledge based STAP

The conceptual diagram of the knowledge –based STAP(KB-STAP) is shown in figure. Radar data enters the KB-STAP from the receiver elements. KB-STAP accepts inputs from other knowledge sources such as mapping data, flight profiles, communication systems, navigation systems etc.

Knowledge information is first directly used to pre-adaptive processing. Knowledge information such as mapping data indicate the presence of known discrete or ground traffic.

After that there is a non-homogeneity detector which is used to determine whether the clutter is a homogeneous one or non-homogeneous. Then the homogenous cells and non homogenous cells are differentiated and kept. Algorithms used are different for homogenous clutters and non homogenous clutters. Select the appropriate clutter suppression algorithm in each case and then apply it to the radar data.

3.6. Technique Based on Subspace Projection

In this section we describe a technique based on subspace projection which is used to suppress the homogenous clutter. This uses an observation that the clutter returns are range dependant, because it exists at all ranges of interest, to obtain an improved estimate of the covariance matrix R(u) from measured data x{r}.

The subspace technique is based on the theory of subspaceprojection in three dimensional geometry. Consider a point P(x,y,z) in XYZ space. If this point is projected on to an orthogonal plane, say xy plane the z co-ordinate will be eliminated. This means that this is another form of representing the point P(x,y,z) using different basis vectors. Same is the case with received data, which is a 3 dimensional matrix which contains clutters, jammers, and target data. The clutter subspace and jammer subspace are orthogonal to each other because they are independent vectors and satisfy the properties of orthogonality. Therefore if the received data is firstly projected on to a subspace orthogonal to clutter subspace that is jammer subspace then the clutters can be eliminated. And the jammer can be easily nulled out from the resulting signal to make it a useful signal.

4. FUTURE WORKS

The actual matrices are very large in size and this favorable for more accurate results. But the computational load is very high. In order to decrease the computational complexity we have to deal with matrices of small dimensions. Researchers are concentrating on this area of reducing the rank.

The STAP technologies which are implemented currently concentrates on dealing with single clutters. The technology of STAP can be extended to suppress multiple clutters and in the case of multiple targets are there. The knowledge based STAP utilizes information obtained from other resources also along with the real time data. Application of artificial intelligence to the system is now on studies.

5. CONCLUSIONS

Space time adaptive processing is found to be an optimum solution for detecting the moving targets using airborne SAR. And the space time filtering provide better performance than the conventional high pass Doppler filtering. Also the STAP does require high pulse repetition ratio which helps in effective detection.

Various approaches to STAP are studied in detail. Each method has its own advantage and may have some disadvantage. When we use that particular technique we have to compromise that drawback depending upon our area of interest.

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