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Space-Time Adaptive Processing for GPS anti-jamming Receiver

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Abstract

A space-time adaptive processing (STAP) algorithm which can reject interference in spatial domain as well as temporal domain has been widely used in GPS anti-jamming system. According to the characteristic which GPS signal power is far less than the interference signal power, we adopt the subspace orthogonal algorithm in the space-time blind adaptive beamforming. Computer simulation results show that the algorithm can produce filter weight coefficient adaptively in both a simplex spatial filtering and STAP, which reject interference effectively. Simulation results also indicate that using this algorithm, STAP can reject interference of temporal and spatial signal at the same time without GPS signal degradation.

Keywords:STAP; Interference suppression; Subspace orthogonal

1.Introduction

The Global Position System (GPS), who originally designed for the US military in the 1970s, has been increasingly applied to military and civilian areas nowadays. GPS signals are direct sequence-spread spectrum (DS-SS) modulated with Pseudo-Random Noise (PRN) codes [1]. For the low cross-correlation values of PRN code, relatively low powers can be transmitted by the satellites and still be captured and tracked by GPS receivers.

As the GPS signal power is relatively low, the GPS system is more vulnerable to interference. Therefore, to study the anti-jamming technology of GPS systems will be of great significance.

The traditional anti-jamming technology uses time and frequency domain filtering, which is implemented in the digital IF. And it mainly used DFT techniques, front-end filtering technique, achieving the RF interference check-up with AGC and so on. The anti-jamming technology in time and frequency domain can filter the interferences out of band of desired signal. And it is easy to achieve these with low cost. But these technologies are powerless in the case of wideband interference suppression.

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Nowadays, the adaptive antenna array is used most widely for GPS receivers. It includes a number of antenna elements whose gain and phase can be adjusted adaptively according to different environment. Thus, nulling toward the interference direction is gotten in antenna pattern so as to offset the interference.

However, the spatial filter also has shortcomings. Firstly, M antenna elements can only produce M-1 nullings which is the largest number of interference that can be eliminated by the antenna array; secondly, if the interference source is close to the direction of arrival (DOA) of GPS satellite signals, the nulling will damage the GPS signal until the signal is unavailable [2].

Currently, space-time adaptive processing (STAP) technology for GPS receivers has been widely concerned. STAP greatly increased the antenna array freedom degree without adding antenna elements. Thereby, the number of interference that can be handled is increased [3]. STAP represents the development trend of anti-jamming technology for GPS receiver. And the performance of STAP system depends on the adaptive beamforming algorithm which controls the adjusting of weight coefficients of antenna array elements. The beamforming algorithm's convergence speed, steady-state response and the ability of interference suppression determine whether the system is working effectively. So, how to get a suitable adaptive algorithm becomes a research focus.

In spatial filtering, the classic adaptive algorithms include LMS, RLS, and direct matrix inversion (DMI), orthogonal projection and so on. All these algorithms require the prior information like the reference signal or the DOA of signal, so it is not suitable for GPS receiver. Blind adaptive algorithms which do not require any prior information mainly include power inversion algorithm, subspace orthogonal algorithm and so on. These algorithms have aroused extensive concern in the research of GPS anti-interference.

This paper based on the subspace orthogonal algorithm. First, we analyzed the performance of this algorithm in space interference suppression. Then, the subspace orthogonal algorithm is applied to STAP, and we study this algorithm's performance for suppressing spatial and temporal interference at the same time. Last, we verify the effectiveness of the algorithm by simulation.

2.Stap algorithm principle

The GPS space-time receiver is composed by an array of M omnidirectional antennas, each of which is followed by a proper chain of Radio Frequency (RF) components, signal conditioning systems, samplers and digital devices, such that a vector of M baseband signals (complex envelopes) denoted by $x[n] = [x_1[n], x_2[n], \ldots x_M[n]]^T$, is available at the beamformer input for processing, where $x_m[n]$ is the n-th signal sample at the m-th antenna.

STAP, whose structure is depicted in Fig.1, is an effective space-time signal processing technique to reject interference; it acts at the same time as a spatial filter and as a temporal equalizer [4].

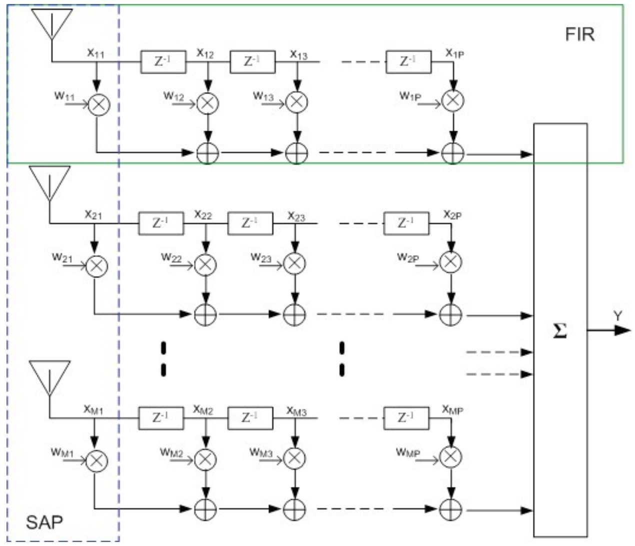

Fig.1. STAP model

In Fig. 1, each antenna element has P time delay units. The data to be processed use the form of subsection input. And the length of data subsection is L, i.e. L times sample data processing for each input. In this way, the amount of data processing each time is M x L dimensions. The data after delay process is converted to MP by (L-P +1)- dimensional matrix, which denote as the symbol X that is X=$[x_{11}(n),\cdots,x_{1P}(n),\cdots,x_{M1}(n),\cdots,x_{MP}(n)]$. W is the weight vector (MP by 1 dimension).

After STAP processing, the output data of array can be expressed as:

$$Y(n) = W^H X \tag{1}$$

In which, X=$[x_{11}(n),\cdots,x_{1P}(n),\cdots,x_{M1}(n),\cdots,x_{MP}(n)]^{\mathrm{T}}$, $W = [w_{11},\cdots w_{1P},\cdots w_{M1},\cdots w_{MP}]$.

Since the enormous computation and high complexity of STAP, to find a suitable adaptive processing algorithm and to obtain the optimal solution of the weight vector of W accurately is a key technology in STAP research.

3.Subspace Orthogonal Algorithm

A subspace technique is used to remove strong interference by projecting the input signal x(n) onto a subspace orthogonal to the interference subspace.

The principle of rejecting interference in subspace orthogonal algorithm is depicted as follows [5] [6].

Suppose the elements number of adaptive antenna arrays is M, after down conversion and ADC (Analog-Digital convert) sampled, signal model can be expressed as:

$$X(n) = \sum_{k=1}^{K} S_k(n)a_k(n) + \sum_{l=1}^{L} J_l(n)d_l(n) + N(n) \tag{2}$$

In which, $X(n) = [x_1(n), x_1(n), \cdots, x_M(n)]^T$ is the data which is received by M array elements. $s_k(n)$, $a_k(n)$ is amplitude and direction vector respectively of the k^{th} GPS signal. $j_l(n)$, $d_l(n)$ is amplitude and direction vector respectively of the l^{th} jamming signal. K is the total number of received GPS signal. L is the total number of interference signals. And $N(n)$ is Gaussian white noise with 0 mean and $\delta^2\,\mathrm{I}_M$ variance.

Assuming GPS signals and interferences and background noise are uncorrelated with each other, the cross-covariance matrix R of equation can be written as:

$$R_{xx} = E\{X(n)X^H(n)\} = R_S + R_J + R_N \quad (3)$$

Where E{*} denotes the expectation, H denotes the Hermitian transpose, Rs, R_J and R_N are the contributions of GPS signals, interferences and noise in the overall cross-covariance respectively, The matrix R_{xx} is a positive-definite matrix, so it has an eigen decomposition give as

$$R_{xx} = \sum_{i=1}^{M} \lambda_i e_i e_i^H \quad (4)$$

Where, e_i is the eigenvector corresponding to eigenvalue λ_i, and the eigenvectors e_1, e_2, … e_M are orthogonal to one another.

λ_i is arranged from big to small, then

$$R_{xx} = \sum_{i=1}^{L} \lambda_i e_i e_i^H + \delta^2 \sum_{i=L+1}^{M} e_i e_i^H \quad (5)$$

In the GPS case, the power of GPS signals is well below the background noise, and the power of interference is much stronger than that of background noise, that is, interferences are dominating in the overall cross-covariance matrix R_{xx}. Therefore, after eigen decomposition of R_{xx}, the L biggest eigenvalues ($\lambda_1, \lambda_2, ...\lambda_L$) correspond to L uncorrelated strong interferences, and $\lambda_{L+1}, \lambda_{L+2}, ...\lambda_M$ correspond to background noise and GPS signals. The eigenvectors e_1 , e_2, … e_L compose M by L interference subspace, e_L , e_{L+1} …, e_M form M by (M-L) signal subspace.

The interference subspace and signal subspace are orthogonal to each other. Therefore, we can project the received signal $x(n)$ onto signal subspace, so that the strong interference will be removed.

Let the array weights be

$$w = \sum_{i=L+1}^{M} C_{i-L} e_i \quad (6)$$

Then $w \perp span\{ e_1, e_2 \cdots e_L \}$.

According to equation (1) and (2), there are:

$$Y(n) = [\sum_{k=1}^{K} S_k(n) a_k(n) + \sum_{l=1}^{L} J_l(n) d_l(n) + N(n)]^H w = [\sum_{k=1}^{K} S_k(n) a_k(n) + N(n)]^H w \quad (7)$$

In accordance with the orthogonality, we can use the characteristics of weak GPS signals and strong interference signals to obtain array output Y(n), which has successfully suppressed the strong interference signals.

4.Stap algorithm Simulation

4.1.GPS Signal Model

The pseudo random noise sequences (PRN) of GPS satellite signal includes C/A code and P code, in which P code is confidential and open exclusively to authorized users. Therefore, only the study of the civil signal modulated with C/A code on the L1 carrier frequency band is considered in this paper. The GPS C/A code signal can be modeled as[7]

$$x(t) = \mathrm{Re}\{\sqrt{2P_s}\, d(t) PN(t) \exp(j2\pi f_c t)\} \quad (8)$$

Where P_s is the transmitted signal power, d (t) $\in$ {−1,1} is the binary phase-shift keyed (BPSK) data modulation at 50bit/s, and f_c is the L1 carrier frequency.

Consider a linear antenna array with antennas equidistant along the y-axis as show in figure 2. The spacing between each antenna element is d, which is half of the wavelength λ ($\lambda = c/f_0$, c denotes the speed of light). The number of antenna elements is M.

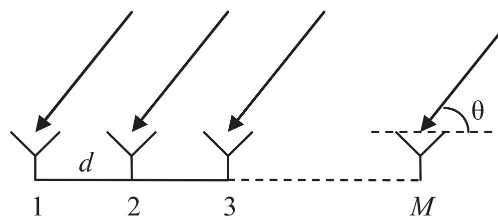

Fig.2 Linear Array with Equi-space

The vector of the m^{th} antenna's coordinates u_m in space is $u_m = [x_m, y_m, z_m] = [0, (m\text{-}1)d, 0]$, Assuming the azimuth of incident signal, the signal direction vector on antenna array elements can be expressed as[8]:

$$a(n)=\begin{bmatrix}1\\ \exp\{j\frac{2\pi}{\lambda}(\sin\theta)d\\ \vdots\\ e\,\mathrm{xp}\{j\frac{2\pi}{\lambda}(\sin\theta)(M-1)d\end{bmatrix} \tag{9}$$

In the STAP simulation, each antenna array element contains P time delay elements. And MP by 1 dimensional discrete input vector is defined $x(n)$ ($n = 1, 2, ..., N$) as following:

$$x^T(n)=[x_{11}(n),...,x_{1P}(n),...,x_{M1}(n),...,x_{MP}(n)]$$

In which, N is the data segment length. $x_{mp}(n)$ is n^{th} sample of p^{th} delay element in m^{th} array element ($n = 1, 2, ..., N$), the input data matrix of array is:

$$\boldsymbol{X} = [x(1), x(2), \dots x(N)]^T \tag{10}$$

4.2.The Spatial Filter Simulation

Spatial adaptive beamforming is an effective spatial signal processing technique to reject interferences when the DOA's are different to those of the desired GPS signals. However, when the interference signal's direction close to the direction of GPS signals, GPS signals be also suppressed simultaneously. The closer the GPS signal is to the interference, the greater the degradation is. The following simulation verifies this point.

We consider a linear antenna array with 8-element as shown in figure 2 and assume as follows: there are two strong interferences in received signal. Interference signals appear in the directions of -20° and 30°. Interference noise ratio is 10dB. GPS signal's incident direction is 60°. And the SNR is -20dB. Then using the subspace orthogonal algorithm can gain antenna array pattern as Figure 3:

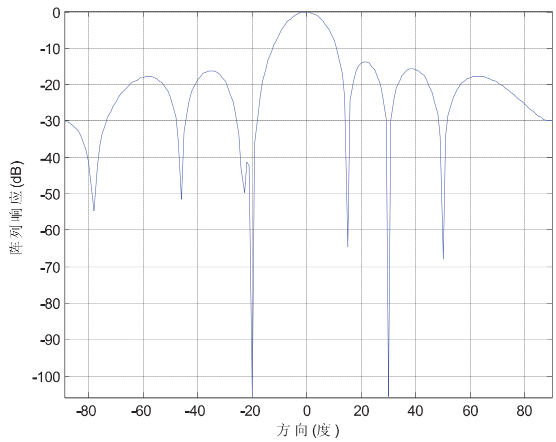

Fig.3. null pattern under two jammers

From Figure 3, it can be seen that the antenna array produced nulling in the directions of -20° and 30° and eliminated the interference signal. This shows that the subspace-based orthogonal spatial adaptive beamforming algorithm can effectively suppress interference signals in different directions.

Then, the direction of interfering signals is presumed to remain unchanged, GPS signal direction is -16.36° ($\pi/11$), the pattern shows in Figure 4:

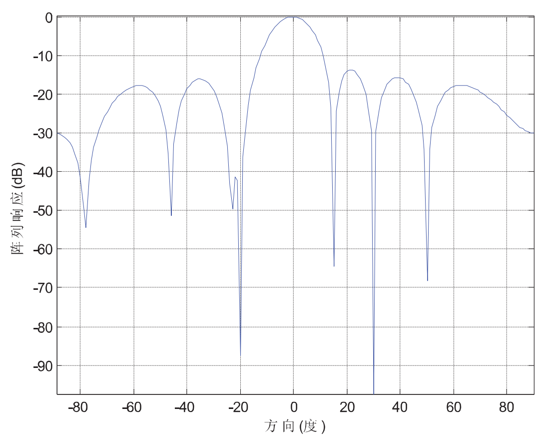

Fig.4 null pattern for GPS signal is closer to jammer

According to Figure 4, the antenna array still has nulling in the interference direction of -20°. The spatial nulling technique rejects the interference but also degrades the GPS signals.

4.3.STAP Performance Simulatio

The principle of STAP has been introduced in section II. In this paper, we proposed to apply the subspace orthogonal algorithm in order to obtain the weight coefficients. The following simulation shows the effectiveness of the method.

Assuming the direction and intensity of GPS signals and interference signals in the array received data are consistent with that in Figure 4. Namely, the direction of GPS signal is -16.36°, and the two interference signals come from the direction of -20°and 30°. Since time-domain filtering only can filter out signals outside of the band, so we suppose that the frequency of the first interference signal (which is close to the direction of GPS signal) is 1.5 times as high as that of GPS signal. The number of antenna array element is 8. And the time delay unit was set as 17 and 63 respectively. Then, the input data of array elements is obtained by the equation (2) and (10). And using the subspace orthogonal decomposition algorithm gets weight vector w, and then get the patterns of the antenna array elements as Figure 5, 6:

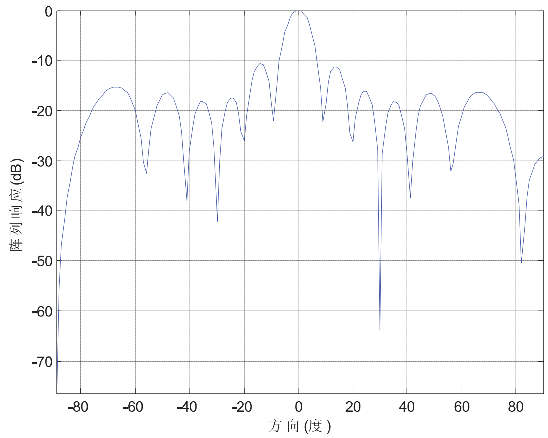

Fig.5 Time delay is 17

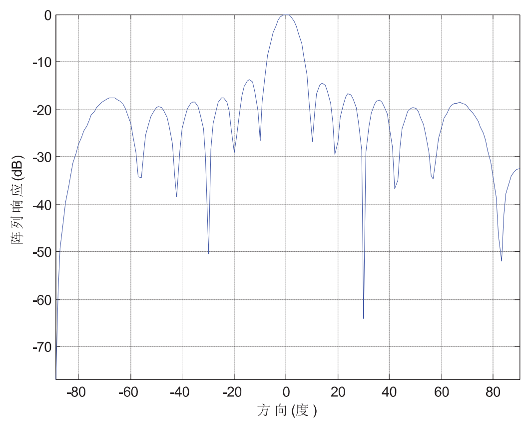

Fig.6 Time delay is 63

In Figure 5 and 6, we can see that the antenna array pattern does not have nulling in the direction of -20°, so it will not degrade the GPS signal near this direction. It shows that: first, the delay unit in time domain filtered out interference signals outside of the GPS signal band in the space-time joint beamforming algorithm, and then the nulling produced by the antenna array filter out interference signals. The simulation results also show that the filtering weight coefficients in temporal and spatial domain are obtained at the same time by using subspace orthogonal algorithm, which can effectively suppress interference in temporal and spatial domain.

5.Conclusion

STAP techniques, whose one of the key issues is to obtain the weight coefficients adaptively, have been widely studied in different areas. First, this paper analyzed how to apply STAP techniques in the research of GPS anti-jamming. And then, we proposed a method to get weight coefficients of beam forming using subspace orthogonal algorithm according to the characteristics that GPS signal's power is much lower than interference noise signal's power and GPS and interference signals are unrelated. Simulation results show that STAP compared with simplex spatial filtering techniques can effectively suppress interference in spatial and temporal domain simultaneously. And using the subspace orthogonal algorithm can get weight coefficients in a fast and adaptive way without any requirement for prior information of GPS signals.

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References

[1] Elliott D.Kaplan, Christopher J.Hegarty, Understanding GPS: Principles and Applications (2nd Edition) [M], Artech House, Inc, 2006.

[2] Liu Wenlin, Chang Qing. Implementation of STAP algorithm based on FPGA of anti-jamming GPS receiver [J], space electronic technology, 2008.02.

[3] Sun Xiaochang, Huangfu kan, Chen Qing, Joint space-time adaptive filtering for GPS anti-jamming receiver, Journal of China Institute of Communications, vol.25, No.8, August 2004.

[4] Emanuela Falletti, A novel blind adaptive space-time receiver for multi-code DS-CDMA [J], IEEE Transactions on wireless communications, vol.5, No.2, Feb, 2006.

[5] Lu Yan-e, Yang Jun, Ding Zi-ming. The orthogonal weighted algorithm for GPS receiver anti-jamming [A]. CIE International Conference on Radar, Beijing, CIE Press, 2001.

[6] Riou C, Chonavel T. Fast adaptive eigenvalue decomposition: A maximum likelihood approach [A]. IEEE International Conference on Acoustics, Speech, and Signal Processing [C]. 1997.

[7] SEUNG-JUN KIM, RONALD A.ILTIS, STAP for GPS Receiver Synchronization [J], IEEE Transactions on Aerospace and Electronic Systems, vol. 40, No.1, Jan. 2004.

[8] Yaohua Zheng, Adaptive antenna Array processing for GPS receivers [D], the University of Adelaide, July, 2008.