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ALE-FFT ALGORITHMS FOR WEAK SIGNAL ACQUISITION

Pan Xi

Beijing Institute of Technology, Beijing 100081, China

ABSTRACT

Weak signal acquisition is the key problem of deep space detection. The paper discusses an improved weak signal acquisition technology which fits for acquiring the signals having high dynamic range and low signal to noise ratio (SNR). The adaptive line enhancer is applied before the FFT acquisition to improve the acquisition performance and reduce the acquisition time. The output SNR and the dynamic detection ability are enhanced by using the appropriate adaptive line enhancer. Aiming at the residual carrier, the acquisition methods that use the ALE-FFT and normal FFT are compared, the improved FFT acquisition algorithm has better acquisition performance. The spectrum estimation algorithm is discussed also.

1. INTRODUCTION

In deep space detection, due to the long distance and the noise in space the received signals are so weak and have low signal to noise ratio (SNR) and high carrier phase noise. The existing method for deep space detection is to enhance transmitting power and enlarge the equivalent antenna caliber, then the higher carrier to noise ratio (CNR) can be achieved by transponder. But this CNR is also low to fit for the deep space communication. On the other hand, the speed of space vehicle exceeds the second cosmic speed, especially for X and Ka frequency bands, the signals have large Doppler dynamic range and the signal acquisition is more difficult for deep space application. The paper uses an improved FFT acquisition algorithm which the adaptive line enhancers (ALE) are used before FFT to improve the detecting signal to noise ratio. The residual carrier demodulation is mainly discussed. The simulations are finished to prove that ALE-FFT algorithm has great improvement in detection ability than normal FFT acquisition.

Because the signals from deep space are so week that the FFT analyzing bandwidth must be so narrow which gets to 0.1 Hz at least and the Doppler frequency dynamic range is wide, the conventional 1024 points FFT that covers hundred Hertz bandwidth can not satisfy the needs of deep-space communication any more. The FFT points used in week signal acquisition for deep space are far more than 2^{10} that is ultra-long point FFT.

2. ALE-FFT ALGRITHMS

2.1. Adaptive Line Enhancers

In residual carrier acquisition mode, the ALE is equivalent to an adaptive band-pass filter which enhances the acquisition SNR greatly. The paper uses the first algorithm of ALE as the optimal adaptive filter in [1] and [2]. The algorithm does not need the prior knowledge of received signals, such as SNR, Doppler frequency and sweeping rate of carrier frequency. The structure of adaptive filter is shown in Fig. 1[1] which based on the least-mean-squares (LMS) algorithm [3] and the coefficient of filter can be set adaptively.

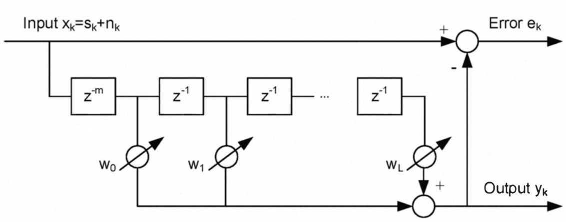

Fig.1. Structure of Adaptive Line Enhancers

Where, input of filter

$$x_k=s_k+n_k \tag{1}$$

s_k is carrier component and n_k is white noise component with power σ_n^2;

The output of filter

$$y_k = w_k^h x_{k-m} \tag{2}$$

$w_k = [w_0 w_1 \cdots w_L]^T$ is the coefficient vector of L tap filter.

The filter coefficients are updated using the follow formula:

$$w_{k+1} = w_k + 2\mu e_k x_{k-m}^* \tag{3}$$

where μ is the step size of iteration and is defined as follows:

$$0 < \mu < \frac{1}{(L+1)Power_{signal+noise}} \tag{4}$$

The error sequence

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$$e_k = x_k - y_k \tag{5}$$

The ALE system output CNR is obtained as [1]:

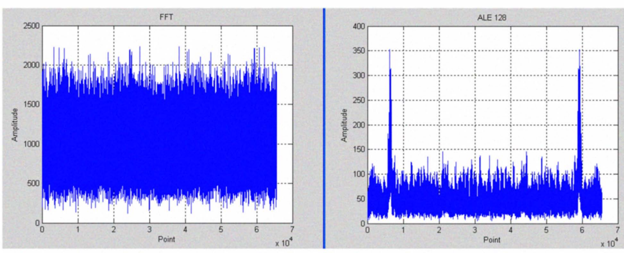
$$SNR_{out} = \frac{(L+1)Power_{signal}}{Power_{noise}} \tag{6}$$

The steady-state CNR gain is

$$G_{ALE} = L+1. \tag{7}$$

2.2. FFT vs. ALE-FFT

The purpose of introducing the ALE above is to lead this algorithm for deep space acquisition, using the ALE before FFT algorithm can get better performance than conventional FFT, the performance is shown in Fig.2.



Conventional FFT ALE-FFT

Fig.2. FFT vs. ALE-FFT (C/N_0=25dBHz, α=1000 Hz/s)

The received CNR is 25dBHz and the dynamic range α=1000, the ALE length is 128. Figure 2 shows that ALE-FFT algorithm can improve the detection ability of Doppler dynamic range and satisfy the need of Doppler acquisition which in the state of high dynamic range and low CNR.

3. SIMULATION AND DISCUSSION

3.1 Simulation

The performances of the ALE-FFT which have different filter length with different CNR are studied by simulations. Three kinds of CNR conditions which is 40dBHz, 25dBHz and 20dBHz are shown in table1,2 and 3. The number of points of ultra long point FFT is 65536, the resolving band wide (RBW) is 2Hz.

The following three tables show the performance comparison when using FFT, 64-tap ALE-FFT and 128-tap ALE-FFT on the condition of different dynamic range. ALE64_FFT means 64-tap ALE then FFT algorithm, ALE128_FFT means 128-tap ALE then FFT algorithm. Five kinds of dynamic ranges are analyzed.

Tab.1. C/N_0=40dBHz, RBW=2Hz

Dynamic range of Doppler frequency(Hz/s)		0	100	200	400	800
Output SNR	FFT	38.0	18.1	15.7	—	—
	ALE64_FFT	57.1	36.3	34.1	31.1	28.6
	ALE128_FFT	59.6	38.7	36.4	33.2	30.0

Tab.2. C/N_0=25dBHz, RBW=2Hz

Dynamic range of Doppler frequency(Hz/s)		0	100	200	400	800
Output SNR	FFT	23.3	—	—	—	—
	ALE64_FFT	31.1	17.7	17.8	16.0	16.3
	ALE128_FFT	35.8	21.4	22.0	20.7	19.3

Tab.3. C/N_0=20dBHz, RBW=2Hz

Dynamic range of Doppler frequency(Hz/s)		0	100	200	400	800
Output SNR	FFT	18.6	—	—	—	—
	ALE64_FFT	17.3	10.8	9.7	9.2	—
	ALE128_FFT	23.1	14.0	14.3	13.2	—

Note: "—" represents fail to acquisition.

According to the theoretical calculation, the gain of 64-tap ALE and 128-tap ALE are calculated as follows:

64-tap: 10×log64=18dB

128-tap: 10×log128=21dB

Some conclusions can be made from Tab.1,2 and 3:

(1) When CNR is greater (above 40dBHz) and dynamic range of Doppler frequency is lower than 400Hz/s, the ALE gains G_{ALE} match the theoretical value and as the CNR is reduced, the simulation ALE gains is lower than theoretical value.

(2) 128-tap ALE-FFT algorithm gets 3dB more gain than 64-tap ALE-FFT

(3) On the same CNR, the ALE-FFT algorithm can detect wider dynamic range of Doppler frequency than conventional FFT algorithm.

3.2 Testing results of real acquisition system

The data from the real acquisition system is analyzed and the carrier frequency is 0.23MHz, the sampling frequency and system clock are 0.93MHz, the FFT points is 65535, and the RBW is 2Hz. Tab.4 and Tab.5 compares the performances of FFT, 64-tap ALE-FFT and 128-tap ALE-FFT when CNR is 25dBHz and 20dBHz. The acquisition algorithms are implemented on FPGA of STRATIX II.

Tab.4. C/N_0=25dBHz, RBW=2Hz

Dynamic range of Doppler frequency(Hz/s)		200	400	800
Output SNR	FFT	—	—	—
	ALE 64_FFT	26	22.7	23
	ALE 128_FFT	29	25.5	25

When the CNR is 25dBHz, 64-tap and 128-tap ALE can detect the signal with α =800Hz/s.

Tab.5. C/N_0=20dBHz, RBW=2Hz

Dynamic range of Doppler frequency(Hz/s)		200	400	800
Output SNR	FFT	—	—	—
	ALE 64_FFT	14.6	15.0	—
	ALE 128_FFT	17.2	16.4	—

Note: "—" represents failing to acquisition.

When the CNR is 20dBHz, 64-tap and 128-tap ALE signal can be detected with α = 200Hz/s. The acquisition results of real system are similar with the simulation.

3.3 Power spectrum estimation algorithm vs. FFT

The power spectrum estimation is used to improve the output SNR in the following simulation. The period diagram algorithm is a direct power spectrum estimation method. The estimating power spectrum is

$$\hat{P}_{PER}(k) = \frac{1}{N}|X_N(k)|^2 \tag{8}$$

Where $X_N(k)$ is the spectrum in frequency domain of random signal $x_N(n)$, N is the number of sampling points. Fig.4 and Fig.5 show the comparison of ALE-FFT algorithm and ALE-PSD algorithm. Using power spectrum estimation algorithm, the ALE filter output results are processed.

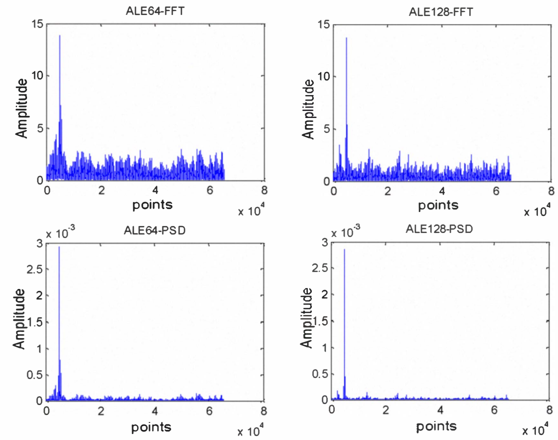


Fig.4. C/N_0=25dBHz, α =200Hz/s, N=65536

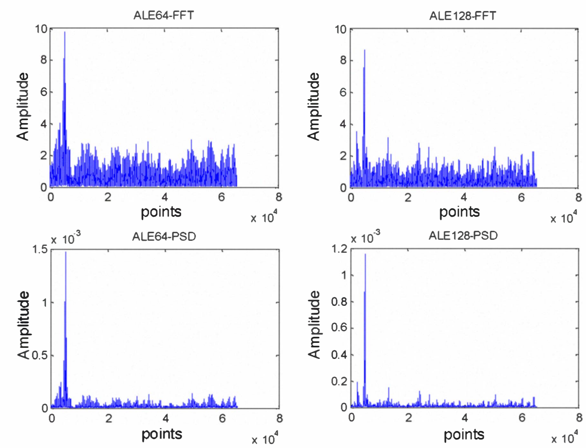


Fig.5. C/N_0=25dBHz, α =800Hz/s, N=65536

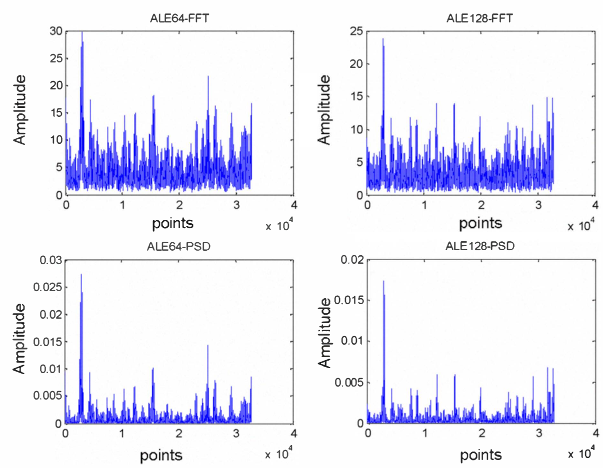


Fig.6. C/N_0=20dBHz, α =200Hz/s, N=32768

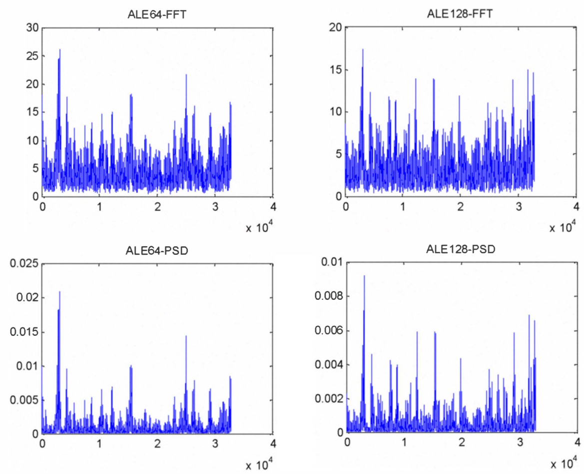


Fig.7. C/N$_0$=20dBHz, α=300Hz/s, N=32768

From the figure 4 to 7, the conclusion can be made that the power spectrum estimation algorithm can improve the detection SNR, but this algorithm can not increase the detection probability because it also can not provide the correct frequency estimation when the ALE-FFT algorithm fails to detection.

4. CONCLUSION

In this paper, ALE-FFT algorithm is discussed to be used in weak signal acquisition for deep space application. The FFT acquisition is a normal method in this case and ALE-FFT algorithm that ALE is added before FFT can enhance the ability of weak signal detection, especially for the weak signal which has big dynamic range of Doppler frequency. The conclusion is made by simulation about the performance of ALE-FFT.

(1) The ALE-FFT algorithm can acquire the weak signal which has lower CNR and larger dynamic range of Doppler frequency than conventional FFT algorithm.
(2) The more the length of ALE is, the better the performance for weak signal detection is.
(3) ALE-PSD can improve the detection SNR when the ALE-FFT algorithm is valid.

5. REFERENCES

[1] H. G. Ych, T. M. Nguyen, "Adaptive line enhancers for fast acquisition," TDA, Progress Report 42-119, pp. 140-159, Nov., 1994.

[2] H. G. Ych , T. M. Nguyen， "Performance Comparison Between Adaptive Line Enhancer and FFT for Fast Carrier Acquisition" TDA

[3] B. Widrow, J. R. Tlover, J. Kaunitz, C.S. Williams, R. H. Hearn, J. R. Zeidler, E. Dong, Jr., R.C.Goodlin, "Adaptive Noise Canceling Principles and Applications," Proceedings of the IEEE, vol.63, pp. 1692—1716, December 1975