Research on Telemetry Carrier Parallel Code Serial Capture Algorithm Based on DTFT

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Abstract. In view of the demand for the acquisition speed of spread spectrum signal in aerospace monitoring and control, this paper studies a serial capture algorithm for carrier parallel code based on DTFT. Through the simulation analysis of the main factors affecting the accuracy of the algorithm’s acquisition, the basis and application conditions of the algorithm parameters are studied.

1. Introduction
In aerospace measurement and control, the synchronization accuracy of spread-spectrum signals has a great influence on the overall performance of the spread spectrum measurement and control system. The initial acquisition is the first step in signal synchronization, and the study of its algorithms becomes critical. This paper studies the acquisition algorithm of spread spectrum unified monitoring and control signals.

2. The principle of the algorithm
In this paper, based on the DTFT-based frequency spectrum estimation method, the FFT-based carrier parallel code serial acquisition algorithm is improved. The carrier acquisition accuracy is improved without increasing the processing data length, and the capture result is not affected by the data jump.

The spectrum corresponding to the DTFT is continuous because it can perform frequency domain conversion on the signal at any frequency point. DTFT is defined as:

$$X(e^{j\omega}) = \sum_{n=0}^{N-1} x(n)e^{-j\omega n} \quad (1)$$

FFT is a fast algorithm of DFT, so the definition of FFT is the definition of DFT:

$$X(k) = \sum_{n=0}^{N-1} x(n)e^{-j\frac{2\pi}{N}nk} \quad (2)$$

By comparing the above two formulas, it can be concluded that the spectrum corresponding to the FFT is equivalent to the normalized spectrum.

$$X(k) = \left[ \begin{array}{c} \sin(M\pi f_c T_s) \\ \sin(\pi f_c T_s) \end{array} \right] \left[ \begin{array}{c} \sin(MN\pi f_c T_s - \pi k) \\ \sin(MN\pi f_c T_s - \pi k / N) \end{array} \right]$$

(3)
The farther the detected frequency point is from the center frequency, the smaller the corresponding spectrum amplitude is. The FFT can be captured first, and then use the DTFT to complete the carrier locking. The specific operation method is shown in Figure 1:

![Capture schematic](image)

**Figure 1.** Capture schematic

Simulation conditions: The length of the PN code is 1023, the transmission rate of the PN code is 1.023 MHz, and the information rate is 1 kbit/s. Do ppler is 59.5 kHz, FFT transform is performed in a PN code period, the estimated Doppler is 59.941 kHz, Doppler as the center, two sides symmetrically take several frequency values, and DTFT is used for carrier acquisition. The Doppler frequency value is 59.541 kHz. The specific capture situation is shown in Figure 2.

![DTFT capture](image)

**Figure 2.** DTFT capture

3. **Doppler Frequency Effect and Simulation Analysis**

It is known from formula (3) that changing the value of Doppler frequency under the condition of unchanged parameters will affect the output peak of the capture algorithm. Figure 3 shows the effect of Doppler frequency on general correlation algorithms (time-domain serial algorithm and FFT cyclic correlation algorithm), FFT carrier parallel code serial algorithm, and DTFT algorithm.
Figure 3. General correlation algorithm, carrier parallel code serial FFT algorithm, Doppler response of DTFT algorithm

From Fig. 3, it can be seen that the output peak value of the general algorithm is greatly affected by the Doppler frequency, and the output peak value at 1 kHz drops to zero, making it impossible to make a correct capture decision. The correlative peak attenuation caused by the Doppler frequency value at each frequency point of the carrier parallel code serial FFT algorithm is compensated, and the Doppler frequency is less affected. There is almost no attenuation at the peak at 1 kHz, which is in accordance with the above analysis result. The DTFT algorithm can not only compensate the Doppler frequency, but also effectively solve the fan-fading phenomenon of the FFT algorithm due to the fence effect, thus improving the accuracy of carrier capture.

4. Effect of Segments and Simulation Analysis

When using the DTFT algorithm, $\omega = 2\pi k / N$ will be substituted into equation (3):

$$X(\omega) = \frac{\sin(M\pi f_d T_e)}{\sin(\pi f_d T_e)} \left| \frac{\sin(MN\pi f_d T_e - N\frac{\omega}{2})}{\sin(M\pi f_d T_e - \frac{\omega}{2})} \right|$$

(4)

Being captured in units of a pseudo-code period, the total data length $L = MN$ is fixed, the above equation can be written as:

$$X(\omega) = \left| \frac{\sin(L\pi f_d T_e)}{\sin(\pi f_d T_e)} \right| \left| \frac{\sin(L\pi f_d T_e - LN\frac{\omega}{2})}{\sin(L\pi f_d T_e - \frac{\omega}{2})} \right|$$

(5)

For the amplitude corresponding to be detected, the larger $N$ is, the larger the corresponding amplitude is. It can be seen that the amplitude corresponding to the frequency point to be detected is affected by the number of segment segments, thereby it affects the capture performance. Figure 4
shows the Doppler frequency response curves for five cases with segment numbers 8, 64, 128, 256, and 512. Higher the segments are, the greater the Doppler frequency compensation is.

Figure 4. Effect of segment number on capture performance (b is an enlargement of a)

5. Noise Effect and Simulation Analysis
As below, the noise immunity of the acquisition algorithm is analyzed by simulating the carrier error at different SNRs, and the effect of the narrowband Gaussian white noise on the DTFT algorithm and the FFT algorithm are compared.

Simulation conditions:
(a) Pseudo code rate 1.023 Mc/s, Doppler frequency 150 kHz,
(b) The SNR is -20dB, -19dB, -18dB, -17dB, -16dB, -15dB, -14dB, -13dB, -12dB, -11dB, -10dB.
(c) The number of segments is 512, and the DTFT frequency search accuracy is 300 Hz. At each SNR condition, 10,000 simulations were performed and the carrier estimation error was counted.

Figure 5. Effect of noise on capture performance

The conclusions are drawn through simulation:
(a) Under the same segment number, the carrier capture accuracy of the DTFT capture algorithm is significantly higher than that of the FFT capture algorithm, whether it is a high signal to noise ratio or a low signal to noise ratio.

(b) When the signal-to-noise ratio is higher than -19 dB, the carrier acquisition accuracy is hardly affected by noise. The main causes of the error are the “fence” effect of the FFT algorithm and the frequency selection accuracy of the DTFT algorithm.

(c) In the lower signal-to-noise ratio, the download estimation error of the wave increases with the decrease of the SNR, but the carrier estimation error of the DTFT algorithm is still significantly smaller than that of the FFT algorithm.

6. Software Algorithm Processing Speed Analysis

DTFT is an algorithm that processes samples in real time. For example, to estimate the frequency spectrum of m frequency points, the amount of data is N. When a sample value reaches to the complex multiplication, the coefficient one must first be calculated. This requires a complex multiplication of m times, and then the coefficient is multiplied by the sample value. This requires m complex multiplications, and finally adds the result to the previous result. This requires m complex additions, so a total of 3m complex operations are performed.

When the software is implemented, in order to increase the processing speed, the complex multiplication factor may be obtained in advance according to the selected frequency to be measured, and the multiplication result of each segment may be directly multiplied, which saves m complex multiplications. The FFT carrier capture results are processed. The general carrier capture resolution can reach 300 kHz or 500 kHz. For the 1.023 Mc/s code rate, the theoretical linear frequency range of AFC is -1 kHz to +1 kHz, and the frequency capture accuracy should be less than Rb. To improve reliability, select a more precise range. Taking 300 kHz as an example, a 128-point FFT is performed, and the carrier capture resolution is 1 kHz. Assuming that the number of frequency points to be measured is four, multiplication with 128 accumulated values requires 128*4=512 complex multiplication operations, and complex addition requires 512 times. The final total computation is 512 complex multiplications and 512 complex additions. This calculation differs from the FFT calculation by 4 orders of magnitude. The frequency resolution is improved with a small amount of calculation.

7. Summary

In this paper, the parallel code serial capture algorithm based on DTFT carrier is studied. At the same time, the main factors affecting the accuracy of DTFT software acquisition algorithm, such as Doppler frequency and noise, are simulated and analyzed, and the algorithm parameter setting basis is given. The simulation results prove the correctness and effectiveness of the above algorithm.

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