Direct Acquisition Method of Segmented Configurable BDS P-code Signal Based on FFT Parallel One-dimensional Search

Ren Qi*, Yin Chengxiang, Yu Qian, Peng Yan, Kong Lingjia, Yan Shengxu, Jin Gen
Space Star Technology Co., Ltd., Beijing, China
*Corresponding author e-mail: renqiwd@163.com, cxyin@126.com, yuqian818@126.com, py503@163.com, konglj@163.com, yansx88@163.com, gen_golden@126.com

Abstract—BDS P-code signals direct acquisition is a must-have capability for missile weapons products guided by BeiDou Navigation Satellite System in electronic warfare and navigation warfare environments. The direct acquisition method of segmented configurable BDS P-code signal based on FFT parallel one-dimensional search is to perform FFT operation on BD satellite signal and PRN ranging code under the large uncertainty of P-code phase time, so as to turn the two-dimensional serial search of code phase and carrier Doppler frequency into one-dimensional search of phase and frequency at the same time, which greatly shortens the acquisition time. This method has configurable acquisition ability for different phase time ambiguity, realizes direct acquisition of P-code signal with different time ambiguity, has high flexibility, and improves the acquisition performance of P-code signal.

Keywords—BDS, FFT, Parallel, Segmented Configurable, P-code, Direct Acquisition

I. INTRODUCTION

The missile weapon products guided by the BeiDou Navigation Satellite System (BDS) can still realize the direct acquisition of the BDS P-code signal under high dynamic conditions, which is a must-have capability in the electronic warfare and navigation warfare environment. Its purpose is to ensure that the military BD navigation receiver can still work normally when the C/A code is attacked. Compared with the realization of the acquisition by guiding the P-code through the C/A code, BDS P-code signals direct acquisition has better anti-interference ability and spoofing ability [1]. Therefore, this paper focuses on the fast and direct acquisition of BDS B3P codes. In this paper, the direct acquisition method of segmental configurable BDS P-code signal based on FFT parallel one-dimensional search can effectively shorten the acquisition time through parallel search of code phase and carrier Doppler frequency. The method can also realize the direct acquisition of P-code with different phase time ambiguities by configuring the number of traversals. And the Matlab simulation is carried out to prove the effectiveness of the algorithm.

II. TRADITIONAL P-CODE DIRECT CAPTURE METHOD

For the problem of direct acquisition of P-code signals, the period of the P-code is very long, and only a section of it can be intercepted for correlation operation during direct acquisition. In the process of acquisition, it can only be regarded as aperiodic code, and it is infeasible to realize the method of C/A code signal acquisition based on the circular convolution property of FFT [2]. In order to take advantage of the advantages of FFT calculation, the commonly used methods include the XFAST algorithm [3], the PMF-FFT method [4], and the like.

The XFAST method is to overlap-add the PRN ranging code, and further perform a cyclic correlation operation between the superimposed sequence and the received signal; Since the code chips in the received signal and the code chips overlapped from other sections have little cross-correlation, background noise is introduced, which leads to deterioration of the SNR, and thus to the deterioration of the acquisition performance.

The PMF-FFT algorithm uses partially matched filter banks to realize parallel search in PRN ranging code time domain, and uses a small number of FFTs for spectrum analysis of the partial correlation values output by the matched filter banks to realize parallel search of carrier Doppler frequency offset. However, when the uncertainty of the code phase time is too large (such as ±1s) or the carrier Doppler frequency offset is too large, there are problems such as long acquisition time (tens of seconds) and large consumption of hardware resources.

III. DIRECT ACQUISITION METHOD OF SEGMENTED CONFIGURABLE BDS P-CODE SIGNAL BASED ON FFT PARALLEL ONE-DIMENSIONAL SEARCH

The BDS-B3P ranging code is a aperiodic long code. For aperiodic sequences, the process of correlation operation between two sequences is not a circular convolution operation. At this time, the FFT method cannot be used to realize the parallel correlation of the sequences, but zero-filling is used. Filling technology can solve this problem. Therefore, when designing the direct P-code acquisition method, 2L points of the satellite signal and L points of the PRN ranging code can be taken, and zero-filling to 2L points. The FFT operation is performed on the PRN ranging code and satellite signal respectively to realize the parallel search of the code phase and carrier Doppler frequency. By configuring the traversal times, the direct acquisition of the P-code with different phase time ambiguities is realized. The specific algorithm is designed as follows:

Step a: Down-convert the BD satellite signal to a baseband digital signal, and use the baseband satellite signal bandwidth value of 20.46MHz as the sampling frequency to buffer the 2ms baseband satellite signal. The length of the baseband satellite signal is N=40920 points, and the baseband satellite signal sequence for:

$$S = [s_{0}, s_{1}, \ldots, s_{N-2}, s_{N-1}]$$
For the baseband satellite signals, the baseband satellite signals are equally divided according to the preset number of groups $b=20$, and the data length of each group of baseband satellite signals is $L=2046$ points. The divided 20 groups of baseband satellite signals are spliced every two adjacent groups to obtain new 20 groups of satellite data with a length of 2L. The satellite data after each group of splicing is expressed as:

$$S_p = [S_{n,0}, S_{n,1}, \ldots, S_{n,L-1}, S_{n+1,0}, S_{n+1,1}, \ldots, S_{n+1,L-1}] , n = 0, \ldots, 19;$$

Perform FFT operation on the spliced 20 sets of satellite data to obtain 20 sets of frequency domain satellite data, as shown in Fig.1.

**Step b:** At the same time, with the baseband satellite signal bandwidth value of 20.46MHz as the sampling frequency, the PRN ranging code with the preset duration $a$ is cached. Since the data rate of the B3P is 500bps, a bit flip may occur every 2ms\(^3\). In order to avoid the influence of the data sign bit flip on the coherent operation result during the capture process, the longest coherent integration time is 2ms, so the cache $a=2\text{ms}$ PRN ranging code. According to the sampling frequency and the cache preset duration, the length of the cached PRN ranging code is $N=40920$ points, and the resulting PRN ranging code sample value sequence is $c = [c_0, c_1, \ldots, c_{N-2}, c_{N-1}]$, and the PRN ranging code is divided equally according to the preset number of groups $b=20$, the length of each group of data is $L=2046$ points, as shown in Fig.2.

Each group of data is finally filled with 0 to expand the number of data points to 2L. The expanded PRN ranging code sequence is:

$$c_{zp} = [c_0, c_1, \ldots, c_{N-2}, 0_{1\times L}], \quad 0_{1\times L} \text{means L } 0;$$

FFT operation is performed on the 20 groups of PRN ranging code data after the above-mentioned 0-filling, respectively, and 20 groups of PRN ranging code in the frequency domain are obtained, as shown in Fig.3.

**Step c:** Multiply the 20 groups of frequency domain PRN ranging code and frequency domain satellite data of Step a and Step b in sequence one by one to obtain 20 groups of complex multiplication results, and perform 2L point IFFT operation on each group of complex multiplication results, to implement PRN ranging code correlation operations. In the correlation operation result of the 2L point, the first L point is the effective phase correlation result, and then the data of

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**Fig.1** Grouping splicing and FFT operation of 2ms satellite signals

**Fig.2** 2ms PRN ranging code grouping and and zero-filling

**Fig.3** Each group of PRN ranging code FFT operations
the latter L point is discarded to obtain 20 groups of effective phase correlation result data, and the length of each group of effective phase correlation result data is L, as shown in Fig. 4.

Step d: Extract the 20 groups of effective phase correlation operation results obtained in Step c according to the points under the same code phase to obtain L groups of extracted data with a length of 20, namely:

\[ r = [r_{n,0}, r_{n,1}, ..., r_{n,19}], n = 0, ..., L - 1; \]

Carry out 0-filling operation on the extracted data results of the above-mentioned groups, so that the length of each group of data is extended to the preset length \( d = 32 \), that is:

\[ r_{zp} = [c_{n,0}, c_{n,1}, ..., c_{n,19}, \bar{o}_1 \times 12], \bar{o}_1 \times 12 \text{ means } 12 0; \]

The FFT operation is performed on the data after decimation and 0-filling of the L groups respectively, and the Doppler distribution under the phase of the 32-point coherent code in the L group is obtained, and the corresponding frequency resolution is 333 Hz. Then, perform maximum peak detection on the spectral values of the L group of 32 points to obtain the code phase and Doppler corresponding to the maximum peak value, complete the satellite signal acquisition with a preset duration of 2ms, and transfer to the satellite signal tracking operation stage shown in figure 5.

Since the P-code phase of the BDS receiver is generated by timing the phase time of the dedicated PRN ranging code generation module, and the P-code is a non-periodic long code, the PRN ranging code cannot be cyclically convolved with the satellite signal for code phase search. The accuracy of the phase time timing accuracy of the PRN ranging code module directly affects the accuracy of the P-code signal capture. In order to adapt to different phase time timing accuracy, the P code signal can be captured normally and directly, Step b ~ Step d can be repeated by traversing the PRN ranging code method of \( M \times 2\text{ms} \), and the code phase and Doppler value corresponding to the maximum amplitude can
be obtained. Then, the direct acquisition of the P-code signal is completed. That is, by setting the number of traversals M, the direct capture of the P-code signal with a phase time ambiguity of ±M millisecond can be realized.

IV. ALGORITHM DESIGN VERIFICATION

In order to verify the effectiveness of the method proposed in this paper, the Matlab tool is used to simulate and generate a 2ms BDS P-code satellite signal. In the MATLAB simulation, the Doppler frequency offset is set to 2475Hz, and the method in this paper is used to directly capture the P-code signal. In order to further verify the configurability of the method, the simulation sets the ambiguity of the code phase time timing to ±1ms, ±2ms, and ±3ms, and the chip offsets are set to 13790 chips, 37630 chips, and 54660 chips, respectively is shown in figure 6 to figure 8.

Through MATLAB simulation verification, the simulation results are shown in Fig.1–Fig.3. The statistics of
the results after capture are shown in Tab. I. It can be seen from the figure and table that the time ambiguity of different phases is captured at a frequency bin of 23, which corresponds to 2475Hz; the captured code phases are 13790 chips, 37630 chips, and 54660 chips, and the capture results correct.

| NO. | Phase time ambiguity | Traversal times M | Doppler capture results | Code phase capture results |
|-----|----------------------|-------------------|-------------------------|---------------------------|
| 1   | ±1ms                 | 1                 | 23(2475Hz)              | 13790                     |
| 2   | ±2ms                 | 2                 | 23(2475Hz)              | 37630                     |
| 3   | ±3ms                 | 3                 | 23(2475Hz)              | 54660                     |

V. CONCLUSION

For the direct acquisition of aperiodic long code and high dynamic P-code signal, the traditional method of realizing correlation operation based on the circular convolution property of FFT is no longer feasible. In order to shorten the direct acquisition time of P-code signals and the flexibility of direct acquisition of P-code signals under different phase time ambiguities, the method in this paper can effectively transform the two-dimensional search of code phase and Doppler frequency into phase and frequency One-dimensional search performed in parallel, greatly reducing capture time. By setting the traversal times value M, the direct acquisition of P codes with different time ambiguities is realized, which has high flexibility and improves the acquisition performance of P-code signal.

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