Acquisition design and implement of Beidou B3I signal based on GPU

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Abstract. China's Beidou satellite navigation system (BDS) has developed rapidly in recent years. In 2018, China recently publicized the latest Beidou system space signal interface control file (ICD) of the Beidou B3I. Since the Beidou B3I signal has only been released for a short time, there are no references for its implementation. Based on the research on the development status of signal acquisition at home and abroad, this paper studies the real-time problem of software receivers and optimize the module in the capture process on graphic processing unit (GPU) according to the characteristics of B3I signal, design and implement a Beidou B3I software receiver capture architecture and algorithm based on GPU. By comparing with acquisition on CPU, each computing module achieves a GPU/CPU acceleration ratio of 4-50 times, the overall signal acquisition speed has been improved by 2.5 times, and the real-time performance of Beidou B3I software receiver has been effectively improved. At the same time, aiming at the problem of Beidou signal acquisition accuracy, a secondary capture method is designed to improve the capture accuracy. In addition, an optimization idea based on compute unified device architecture (CUDA) programming is proposed to further parallel computing performance on GPU.

1. Introduction

The BDS-2 includes B1, B2 and B3 bands, of which B1 and B2 are for civilian use and B3 is for military use[1]. With the rapid development of GNSS systems and continuous improvement of signal processing algorithms, the software receiver based on PC only needs to replace the functional modules in the software, which has the characteristics of low cost, good openness and expandability, has become a research hotspot in receiver design. Aiming at the shortcomings of serial acquisition of the algorithm on the CPU, the implementation of the software receiver using the GPU with strong parallel processing capability has been widely used in recent years[2-3].

Beidou B3I is the latest publicly available frequency band in 2018 and with few references about it. When using B3I signal with a sampling rate of 62MHz, the huge amount of data affects the Beidou B3I software receiver’s performance because parallel FFT acquisition costs the large amount of computation and time-consuming and there is few relevant information to introduce it.

Based on the FFT parallel code phase search method and the parallel processing ability of GPU, this paper transplanted Beidou B3I acquisition algorithm to GPU high-performance platform, designed and implemented Beidou B3I signal parallel acquisition algorithm based on CUDA, accelerated and optimized the software receiver of B3I frequency point with 62MHz sampling rate. Finally make it
possible to meet real-time requirements. Meanwhile, for the Beidou system, due to the modulation of the Newman-Huffman code (NH code) on navigation message, its capture performance would be affected. Aiming this problem, we optimized the signal capture process of MEO/IGSO satellite which broadcasting D1 messages to improve capture performance.

2. Parallel-acquisition algorithm of Beidou B3I signal

According to the ICD, the spread spectrum sequence of Beidou new signal system adopts the hierarchical structure of the combination of primary code and secondary code. The primary code uses a pseudo-random sequence code, and the secondary code uses Newman-Huffman code[4]. The C/A code of the Beidou B3I signal has a chip rate of 10.23Mcps, a period of 1ms, which is equal to the length of one chip of the secondary code, and the period of secondary code is 20ms equal to the length of one navigation message data bit[5].

The B3I signal is composed of a “ranging code + navigation message” modulated on the carrier, and its signal expression is:

$$S_{B3I}^j(t) = A_{B3I}C_{B3I}^j(t)D_{B3I}^j(t)\cos 2\pi f_3 t + \phi_{B3I}^j$$  \hspace{1cm} (1)

In the above formula, where the upper corner $j$ is the satellite number, $A$ is the amplitude of the B3I signal, $C$ is the B3I signal ranging code, $D$ is the data code modulated on the B3I signal ranging code, $f_3$ represents the B3I signal carrier frequency, $\phi$ is the initial phase of the B3I signal carrier[6].

Beidou B3I adopts code division multiple access (CDMA) spread spectrum communication technology. All satellite signals use the same center frequency and are modulated by different spreading codes. Signal acquisition is a two-dimensional search process. Currently, commonly used searching strategies include serial search, parallel frequency search, and parallel code phase search strategy. Parallel code phase search strategy replaces the correlation operation of digital correlator by using FFT[7], which greatly improves the efficiency of calculation, and is often used in the design and implementation of software receivers. Formula (2) is the specific transformation process.

$$z(n) = \frac{1}{N} \sum_{m=0}^{N-1} x(m)y(m-n) = IFFT[FFT(x(n))\cdot FFT^*(y(n))]$$  \hspace{1cm} (2)

Figure 1 is the search principle based on parallel FFT code phase.

According to figure 1, the implementation process of the parallel code phase search acquisition algorithm is as follows: First, the received IF signal is multiplied by the local carrier signal to obtain I and Q branch signals. Then, the FFT is performed on the complex signal composed of the signals. Next, Performing FFT transformation on the satellite pseudo random noise code (PRN) signal generated by the local PRN code generator to the frequency domain and then taking the conjugate. And multiply the frequency domain results in the above two steps and perform IFFT, take the modulus as the correlation result. Finally, perform non-coherent accumulation and determine the preset detection threshold to determine whether the acquisition is successful[8]. During the whole operation process, due to the large-point FFT operation and the circular search, there is a case where the calculation resource consumption is too large and the calculation takes too long.
3. B3I signal parallel capture scheme based on GPU
In 2006, NVIDIA released the GPU’s general programming structure CUDA[9]. CUDA allows developers to develop without the need to learn complex graphical programming languages, greatly simplify the GPU development process. Moreover, CUDA is developed based on C language and is compatible with software receivers based on PC platform. Meanwhile, it can process large amounts of data with simple calculations in parallel, which is very conducive to the development of software receivers.

3.1. Design of acquisition algorithm based on CUDA
First, we need to transfer the IF data from the CPU to the GPU. But pay attention when programming with CUDA, if there is a dependent calculation between data and data, that is, the result of the current data is required when calculating the following data, at this point, the GPU will not be able to perform parallel calculations on the data[10]. In this paper, the blocks or functions that can be parallelized are allocated to the GPU, and the parts that cannot be paralleled will be run on the CPU, so that the respective advantages of the CPU and the GPU can be fully used. Although the GPU has strong ability in parallel computing, all the data calculated on the GPU needs to be copied from the CPU, which is the most time-consuming part. Therefore, the data transmission should be reduced as much as possible during optimization. The mapping between the portion of the signal capture on the GPU and the portion of the signal acquisition implemented on the CPU is illustrated from the following tables. The function mapping in the CPU is shown in table 1.

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| Table 1. Function mapping in the CPU. |
|-------------------------------------|
| Map | Function                          |
| Read IF data | Mapping in the CPU |
| Dependent calculation | Store acquisition results |

The function mapping in the GPU is shown in table 2.

| Table 2. Function mapping in the GPU |
|-------------------------------------|
| Map | Function                          |
| Mixer | Mapping in the GPU |
| Correlator | Coherent/Incoherent integration |
| C/A code generator | Carrier NCO |

In this paper, the length of data used for capture is 10ms, the sampling frequency of the processed signal is 62MHz, and so there are 62000 sample points per 1ms of data transferred to the GPU. And 3D search range of satellite signals is: (1) 12 Beidou satellites. (2) The doppler frequency searching range is ±10kHz, the frequency searching step is 500Hz, So the searching times is 41. (3) Search
10230 chips, the search step is half a chip, and a total of 20460 code phases need to be searched. The algorithm flow is shown in figure 2.

**Figure 2.** Schematic diagram based on GPU capture algorithm.

In the figure 2, we can see that in order to reduce the time consumption in the copy process, the locally generated C/A code need to be copied to the GPU calling function cudaMemcpy first, so that each time the data is used, it is not necessary to spend time copying again. Then copy the data that needs to perform FFT and IFFT calculation to the GPU, use the CUFFT library in CUDA and call the cufftExecC2C function for parallel computing. And other modules like exclusive-OR operation on the IF signal and the C/A code, multiply and add the I/Q two-way carrier value data are written in the GPU as corresponding kernel functions, which will minimize the copy frequency. Finally, copy the calculated result from the memory on GPU back to the CPU for non-coherent accumulation.

Next step we need to do is searching for the maximum correlation peak, which is a 2D search range of 41*31000. Copy the non-coherent accumulation data from the CPU back to the memory, calling the cublasIsamax function in the CUBLAS library in CUDA. The function it has to achieve is to get the index number of the first largest modulus in a vector. The first time using cublasIsamax function to calculate 31,000 points in parallel, which only needs to count 41 times, the second time using the function is to calculate the maximum value of 41 points, this method can further optimize the calculation speed.

### 3.2. Secondary capture of B3I signals

The Beidou satellite of type MEO/IGSO broadcasts the D1 navigation message. Since the NH code is modulated on the D1 message, it will have a certain impact on the accuracy of signal acquisition. In order to improve the accuracy of B3I signal acquisition, this paper will capture the signal that reaches the threshold value for the first time in the satellite of MEO/IGSO for a second time, as shown in figure 2. The software receiver will again perform the capture procedure at the position of each half step before and after the currently captured frequency, and find the largest peak among them as the new maximum correlation peak. This method will improve the accuracy of the capture, and provide relatively more accurate doppler value and code phase for the next tracking process.

### 4. Simulation verification and result analysis

#### 4.1. Hardware environment of the simulation
1) Platform environment: This paper uses Visual Studio 2015 platform, CUDA 8.0 for simulation testing, the CPU is an Intel Core i7-6700 chip with a frequency of 3.40GHz. The GPU is GeForce GT 730 graphics card of NVIDIA with a memory capacity of 1024MB and a memory frequency of 5012MHz.

2) Experimental data: The Beidou B3I IF data used in this paper is generated from an analog signal source generator, which sampling rate is 62MHz, and the center frequency is 15.52MHz.

4.2. Simulation results and analysis
The simulation completed the search of 12 channels of the Beidou B3I frequency point, and tested the running time of 1 non-coherent integration of single satellite on CPU and GPU. Choose the parts with relatively large calculation like FFT on local C/A code, generate co-directional and orthogonal carriers, FFT on carrier, Code multiplication, IFFT and search for the maximum correlation peak are selected for efficiency comparison, and the simulation results are shown in table 3.

Table 3. Calculation time of each function module.

| Function module                  | accumulation time | CPU Time(ms) | GPU Time(ms) |
|----------------------------------|-------------------|--------------|--------------|
| C/A code FFT                     | 1                 | 0.469        | 0.1227       |
| Generate co-directional and orthogonal carriers | 1                 | 4.923        | 0.3675       |
| Carrier FFT                      | 1                 | 0.467        | 0.1289       |
| Code multiplication              | 1                 | 2.377        | 0.0431       |
| IFFT                             | 1                 | 0.593        | 0.1413       |
| Maximum peak search              | 1                 | 3.039        | 0.2364       |

As shown in table 3, the same method is used to implement the acquisition function on the CPU and GPU, the CPU cannot meet the real-time requirements for processing 1ms of data. But the calculation speed of each function module on the GPU is significantly higher than that on the CPU. Then satellite signal acquisition is performed on all 12 channels, and the acquisition time of each channel shown in figure 3.

Figure 3. Time of each Channel.

The correlation peak results calculated when using the GPU for signal acquisition are plotted as shown in figure 4. A significant peak can be found, indicating that the signal was successfully captured and the result is correct.

Figure 4. 2D parallel search related peak results.
From figure 3, we can see that the Beidou B3I signal capture speed based on GPU is much higher than that on the CPU, but the overall acceleration effect is not as good as the acceleration effect of each module. The reason for this result is that when executing a program on the GPU, the data needs to be copied from the memory on CPU to the memory on GPU. And after the calculation is finished, the data needs to be copied back to the memory on CPU. This part has a great impact on the efficiency of the program. Therefore, it is necessary to reduce the data transmission between the CPU and the GPU as much as possible. Meanwhile, it is also necessary to reduce the small-scale data transmission, and integrate the fragmented data into a large amount of data transmission as much as possible, maximizing the advantage of parallel computing on GPU, allowing the GPU to process more threads at once and allocate thread blocks and number of threads reasonably[11].

5. Summary

According to the newly disclosed Beidou signal frequency band of B3I, this paper designs and implements the Beidou B3I signal parallel acquisition algorithm based on CUDA, using the parallel architecture of GPU for the problem of poor real-time performance of software receivers based on CPU, and improves the real-time performance of software receivers at high sampling rates. The simulation results show that the software receiver optimized by GPU has an obvious acceleration effect. Under the condition of 62MHz sampling rate and 4bit quantization, the calculation speed of the function modules in the acquisition process has increased by 4-50 times and the entire acquisition process runs 2.5 times faster, enhancing the real-time capture performance of B3I signals. In order to solve the problem that the NH code is modulated on the D1 message of the B3I signal broadcasting by the MEO/IGSO satellite, which acquisition accuracy would be affected, the maximum value is adjusted by a second acquisition method near the maximum correlation peak of the captured result to further improve the accuracy of the acquisition.

As there are many kinds of memory on the GPU, such as registers, shared memory, constant memory, etc. and have their specific characteristics. Storing different types and sizes of data in the appropriate memory in the GPU, will make memories perform their optimal performance, which can further improve the capability and speed of GPU parallel computing, and maximize the real-time performance of the software receiver. In the future research, we will continue to study the software receiver based on GPU, which is conducive to the establishment of a high-performance simulation platform for technology development, algorithm improvement and innovation in the field of satellite navigation, which will greatly improves the efficiency of developers.

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