

New Compress Sampling Algorithm for GPS Signal Acquisition in Frequency Domain

Kou Wei, Wen Zhiping, Zhang Yongxue, BI Bo

Abstract—Due to the large and expensive FFT/IFFT core used in the receiver, the cost of realizing the traditional FFT-based fast GPS signal acquisition method is very high. Although some kinds of averaging correlation algorithm can reduce the instant processing points of FFT/IFFT, their noise performance is not promising. This paper proposed a new compress sampling algorithm with high noise immunity for GPS L1 signal acquisition in frequency domain, which allows a smaller and cheaper FFT/IFFT core for fast acquisition unit, and enhances the signal-to-noise ratio (SNR) due to its “redundancy” structure. Simulation results testify the efficiency of this algorithm: the computational complexity has been efficiently suppressed to only 0.93% of the one resulting from the 2D search method in time domain. At the same time the ratio of the maximal to the second maximal correlation value is improved 8.74% over the DFT algorithm that employs no compression and processes the IF (intermediate frequency) sampled signal directly. That means the probability of false alarm is reduced.

Index Terms—GPS, fast acquisition, FFT, compress-sampling, noise immunity

I. INTRODUCTION

Currently the request to the performance of GPS receiver becomes more demanding. As a result, various new fast acquisition methods emerge quickly. The FFT-based fast acquisition algorithm in frequency domain is the one with more extensive applications and researches. Making use of this technique, acquisition unit can process the correlation data in frequency domain in parallel. Compared with the traditional 2D search method in time domain, its processing speed improves at least by a factor of two [1].

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According to the Nyquist requirement, since GPS L1 signal has 2.046MHz bandwidth, the IF sampling frequency can be approximately 5MHz in general [2]. That means more than 5000 points data could be generated after IF sampling. Therefore, huge points FFT/IFFT core must be used in the design of GPS receiver if the direct FFT-based acquisition method is equipped. Obviously the requirement of low cost and high speed can't be satisfied. Although Starzyk [3] proposed one averaging correlation algorithm which can average the sampled data and reduce the instant processing points of FFT/IFFT, the method depresses the SNR of original signal because of its direct average operation on the IF sampled data.

Firstly this paper describes the structure and principle of the novel algorithm in detail. Secondly the method of compressing a great deal of IF sampled data to Radix-2 less points is introduced. Then it presents a “redundancy” structure which can lighten the bad influence of SNR declining caused by compress sampling. Finally, the simulation results prove the advantage of the novel algorithm on the aspects of computational complexity, acquisition precision, correlation peak and probability of false alarm etc.

II. FFT-BASED FAST ACQUISITION ALGORITHM

FFT-based fast acquisition algorithm in frequency domain can be described as follows [4]:

$$P[m] = IFFT(FFT(r[n]) \cdot FFT(prn[n])^*) \quad (1)$$

where $P[m]$ is the correlation value. The maximum of them will be compared with a certain threshold which based on an acceptable probability of false alarm. If the peak crosses the threshold, system can go into the tracking state. If not the acquisition unit will change the correlative parameters and repeat the above course until condition is satisfied. $r[n]$ means the data obtained by stripping off the reference code and the carrier from received signal. $prn[n]$ is the replica. The * represents complex conjugate.

FFT-based acquisition algorithm changes the traditional 2D search to one dimensional search, thus improves the acquisition speed. But the cheaper less Radix-2 points FFT/IFFT cores can't process the huge quantity of IF sampled data instantly. Although Starzyk's averaging correlation method can alleviate the need to expensive huge

Radix-2 FFT/IFFT cores, the bad influence of SNR descending must be a problem that has to be considered.

III. DESCRIPTION OF THE SUGGESTED METHOD

According to the limitation of the direct FFT-based method and traditional averaging algorithm, this paper proposed a new compress sampling algorithm with a certain redundancy structure which can improve the noise immunity. (It will be written as "RNR structure" for short in the follow) The simulation testifies that the novel method can improve the noise performance of the GPS L1 signal acquisition. This technique equipped with a new ITU (Integer to Up) unit to achieve the compressing average on the IF sampled data. Fig. 1 shows the structure of the ITU unit.

It can be known from the average theory that compressing the M points data to N points means making m times of p points average and n times of q points average, $[p, q] = ITUD(M/N)$, function $ITUD$ (Integral Transform To Up and Down) means ceiling and floor integral conversion. It is similar with $ITUD$ that ITU means only ceiling integral conversion. So $ITU(i \times N/M)$, $i \in [1, M]$ can carry out N groups of values which each has p points or q points equal values. After statistical process if there is a consecutive group of p or q points equal values, p or q points averaging unit is called to make average calculate on the corresponding data in the M points data aggregate. It can get N points compressed new data group after N times of p or q points average.

Next, the averaged p or q points data obtained from the $ITUD$ block will pass through a special counter. Its aim is to find the bigger point number: $\max(p, q)$ and set it as the threshold of the equation judge. If the number of the consecutive points calculated by $ITU(i \times N/M)$, $i \in [1, M]$ equals to $\max(p, q) - 1$, the averaging unit will begin the less points average operation. In contrary, if the point number equals to the threshold, it will compress the more points consecutive data to one data point.

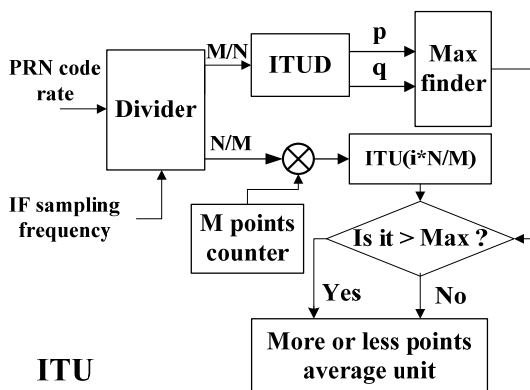


FIG .1 Structure of the ITU

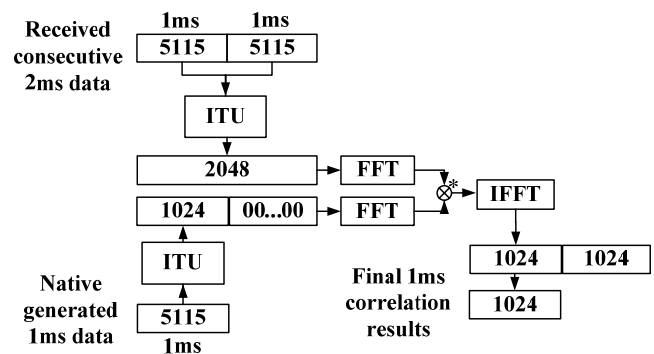


FIG .2 Novel fast acquisition method with RNR structure

After achieving the compress operation on the IF sampled data, the problem of SNR descending will emerge consequentially. If the scale of compression is high, the acquisition result must be influenced by the faint SNR more or less. Therefore aiming at the suggested algorithm, this paper proposes a RNR structure which can enhance the SNR of the being processed signal. Fig. 2 shows a part structure of the novel fast acquisition method with redundancy structure. For explaining expediently, all the description in the following is based on the 5.115MHz IF sampling frequency.

The strategy of this novel algorithm is first to make use of ITU block to compress the consecutive 2ms (10230 points) IF sampled data to 2048 points. The consecutive 1ms replica (5115 points) are compressed to 1024 points through the same processing, then padding another 1024 zeros to form 2048 points data sequence. Calculating 2048-point FFT for both 2048-point sequences and then computing the complex conjugate of the follow one. Next multiplying these results together and taking 2048-point IFFT. At last keep only the first half IFFT results and discard the other half. The final results correspond to the correlation results in frequency domain of the first millisecond. Thus, because the energy of the first 1ms signal is enhanced in frequency domain, the target of reducing the impact of SNR declining can be achieved.

It must be mentioned that because of the 20ms period of GPS L1 signal, there will be a probability of 5% that the above mentioned 2ms processed data could be obtained from two different data periods. If the sign of the modulated data changes, it should impact the FFT analysis in frequency domain and thus lead to the aberrance of the acquisition results. But it also can be seen that the acquisition time of 1ms received data is very short and the probability of the above case is also very low. If the acquisition results are aberrant, acquisition system will begin a new correlation in a very short interval. So it can be said that the novel method is feasible.

IV. SIMULATION

In this paper many simulation analyses including computational complexity, acquisition precision, correlation peak and probability of false alarm etc. are carried out on the novel method. Moreover since the direct DFT correlating algorithm does not compress the IF sampled data, it is selected for the compared object in the analysis on the aspect of reducing the probability of false alarm [5].

A. Acquisition precision and computational complexity

The acquisition distinguish probability of FFT is obtained from the product of the PRN code number in each period and the reciprocal of FFT processed points. Because of the equipment of RNR technique, the final acquisition results are only the first half of the IFFT calculated results. Thus the distinguish probability of acquisition can be given as:

$$f = \frac{2 \times 1023}{N} \tag{2}$$

where N is the number of FFT processed points.

It is can be known from [6] that the computational complexity of Radix-2 points FFT is proportional to $N/2(\log_2^N)$. With the same acquisition distinguish probability, the traditional 2D search method must make $P = 1023/f$ times of slipping correlation and its computational complexity is proportional to P^2 [7]. In addition, the calculation of $ITU(i \times N/M)$ in ITU block consumes the main part of multiplication. We can estimate that its multiplication volume is $N+1$ basing on the description in Fig .1. So if we consider the multiplication volume as the main comparison standard, the computational complexity of the novel method and the traditional 2D search method can be separately given as:

$$A_1 = \frac{3N}{2} \log_2^N + N + 1 \tag{3}$$

$$A_2 = 2P^2 \tag{4}$$

Replacing N with the above f:

$$A_1 = \frac{3069}{f} (\log_2^{2046} - \log_2^f) + \frac{2046}{f} + 1 \tag{5}$$

When the IF sampling frequency is 5.115MHz and

$f = \frac{1}{2^n}$, $n = 1, 2, 3...$ the computational complexity of the novel ITU and the traditional 2D search method (SLIP for short) is separately shown in FIG .3.

Considering the GPS acquisition precision is generally 1/2 code chips. It can be seen from the simulation results in FIG .3 that when $f=1/2$ the ratio of the above two ones is as follows:

$$\frac{\frac{3069}{f} (\log_2^{2046} - \log_2^f) + \frac{2046}{f} + 1}{2P^2} = 0.93\% \tag{6}$$

($P = 2046$) . The novel ITU method reduces the computational complexity exhilaratingly.

B. Correlation process simulation

The simulation of the novel algorithm is based on Matlab and it's correlative parameters are set as follows: C/A code delay is 139 chips (the 7th satellite signal); IF frequency is 1575.42MHz; Bandwidth is 2.046MHz; IF sampling frequency is 5.115MHz; SNR is -16dB (the noise added is Gaussian); The native code offset is 600 chips; The Doppler frequency uncertainty is ± 5.2 KHz and the frequency bin-width is 500Hz; The native Doppler offset is 3000Hz in simulation.

There is one more thing must be mentioned that the same Doppler offset is set for the received consecutive 2ms signal in simulation. In practice the Doppler offset of the two 1ms signals could be a little different. But in the novel algorithm, the final result is just the first half computing results of IFFT. The bad influence produced by the Doppler offset change of the second 1ms signal can be weak. Simulation proves when the Doppler offset change is within 6000Hz, the performance of the novel algorithm is steadily nice.

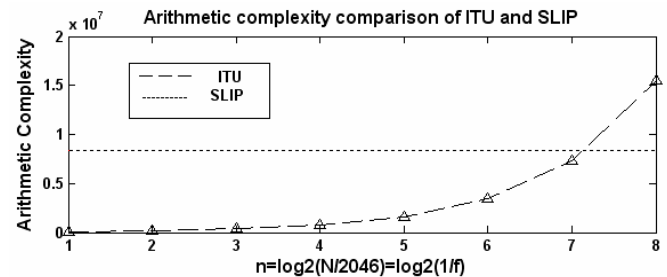


FIG .3 Calculation volume comparing of ITU and SLIP methods

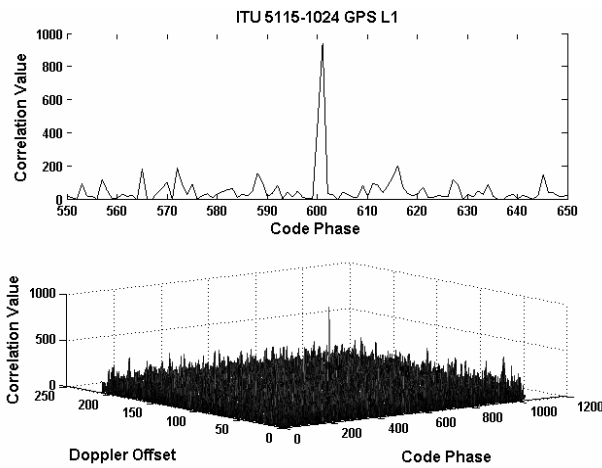


FIG .4 ITU 5115-1024 points acquisition

The fast acquisition results of the novel algorithm are demonstrated in FIG .4 (The above figure is the part around peak).

The max correlation peak appears around the intending position (the 600th FFT point) and its value is high enough. Thus it can be said that the novel ITU algorithm is quite feasible.

C. Probability of false alarm

In literature [3] we know that the larger ratio of the maximal and the second maximal correlation peak value (peak-ratio for short in the follow) means the lower probability of false alarm.

Because the direct DFT correlation method does not compress the IF sampled data, so if the peak-ratio of ITU is larger than that of DFT, it could mean the better noise immunity performance of the novel ITU algorithm.

Specifically the amplitude threshold is set by [8]:

$$V_t = \sigma_n \sqrt{-2 \ln P_{fa}} \quad (7)$$

where P_{fa} is the trial probability of false alarm, σ_n is frequency obtained by calculating using a reference PRN which is known to be absent. So we can see that if peak-ratio is larger, V_t can be set lower. That means a lower probability of false alarm for a fixed σ_n .

FIG .5 shows that the peak-ratios of 100ms data gained from ITU and DFT are 1.493 and 1.373 separately (The one of ITU improves 8.74%). We can see that the RNR structure enhances the SNR and depresses the probability of false alarm observably.

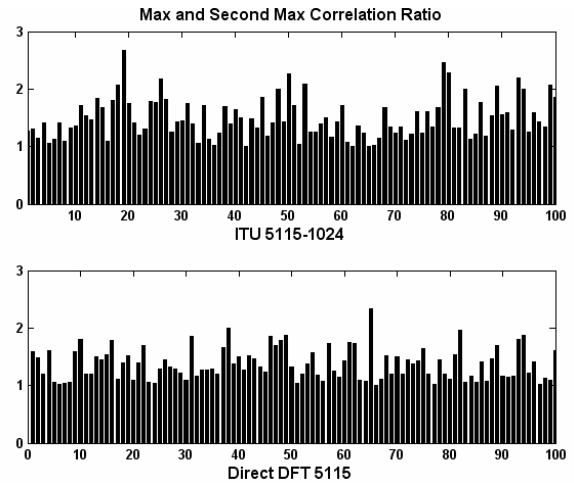


FIG .5 The peak-ratio of 100ms data (ITU and direct DFT method)

V. CONCLUSION

This paper proposed a new compress sampling algorithm for fast GPS L1 signal acquisition in frequency domain. With the novel method, smaller and cheaper FFT/IFFT core can be used to realize the fast acquisition unit. Simultaneously the noise immunity is also enhanced by equipping with the redundancy structure.

The simulation results of Matlab testify that the computational complexity of the novel method has been efficiently suppressed to only 0.93% of the one resulting from the 2D search method in time domain. Moreover the ratio of the maximal to the second maximal correlation value is also improved 8.74% over the DFT algorithm that employs no compression and processes the IF sampled signal directly. According to the analysis on the probability of false alarm, that means a great improvement on noise performance of the novel algorithm.

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