Deep Investigation of Coherent Integral Acquisition Algorithm of GNSS Signals

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***Abstract*—Autonomous navigation places an extremely high demand on the acquisition sensitivity of the global navigation satellite system (GNSS) receivers. To increase the efficiency and sensitivity of the acquisition algorithm of GNSS weak signal, we ipmrove the acquisition algorithm named Improved Acquisition Algorithm with Doppler Frequency Compensation (IAADFC) proposed in our previous study. We provide a detailed analysis and comparison among the proposed IAADFC algorithm, non coherent integration (NCI) algorithm and double block zero padding (DBZP) algorithm. Simulation results show that the weak signal acquisition ability of IAADFC algorithm and DBZP algorithm can be improved by increasing the coherent integration time CIT and the acquisition sensitivity of IAADFC algorithm is higher than that of the DBZP algorithm. What's more, the acquisition sensitivity of IAADFC algorithm and DBZP algorithm can be significantly improved by estimating and correcting navigation message bit flip or transition using DBST algorithm.**

Keywords-GNSS; Improved Acquisition Algorithm with Doppler Frequency Compensation (IAADFC); double block zero padding (DBZP) algorithm

I. INTRODUCTION

The global navigation satellite system (GNSS) is a satellite-based radio navigation system that provides all-weather, high-precision, real-time navigation and location services for all types of carriers on land, sea and air [1].

The long-time coherent integration method is considered to overcome the influence of the square loss and so it is the preferred method to improve the acquisition sensitivity of GNSS receiver[2]. However, there are many problems that need to be overcome.

First, the coherent integration time (CIT) is limited by the navigation message bit length[3]. Some studies have proposed many methods to enlarge CIT, but these methods not only has high computational complexity [4-5], but also have some additional problems, such as missed detection, and false alarm.

Second, The complexity of acquisition algorithm will increase rapidly with the increase of CIT[6].

There are also some studies put forward a symbol combination for bit transition algorithm [7], and a multi-level coherent acquisition algorithm [8] to extend the accumulation time CIT as much as possible[6], but the maximum CIT is still not greater than 1 navigation message bit length. Square loss has become the major factors that affect the acquisition performance in low SNR environments.

Double-block zero padding (DBZP) algorithm try hard to solve the above problems, it try to improve the acquisition sensitivity and at the same time to restrain the quickly increase of time complexity [9]. However, DBZP algorithm requires complex algorithms to estimate navigation message data bit sign transition to reduce the correlation power loss in order to improve the acquisition sensitivity[10]. When the navigation data-bit synchronization problem is considered, DBZP algorithm has a high calculation cost[11].

In summary, acquisition algorithms of GNSS signal have many difficulties in both the acquisition sensitivity and acquisition efficiency. Therefore, we designed a long CIT acquisition algorithm named Improved Acquisition Algorithm with Doppler Frequency Compensation (IAADFC algorithm) in our previous study and relevant achievements have been published in a SCI journal named GPS Solutions in 2018. Based on that achievement. this paper further investigates the long CIT acquisition method to improve both the sensitivity and efficiency of acquisition algorithms.

The rest of this paper is organized as follows. Section 2 analyze the model method of GNSS signal acquisition algorithm. include IAADFC algorithm and DBZP algorithm. Section 3 simulated IAADFC algorithm and also makes a comparison among the IAADFC algorithm, DBZP algorithm and NCI algorithm. Section 4 discuss about Doppler effect on IAADFC algorithm. Finally, Section 6 gives some conclusions and provides some areas for future work.

II. ACQUISITION ALGORITHM MODELING

We will study the long CIT acquisition algorithm we proposed formerly [2] which called IAADFC algorithm, it can estimate the carrier Doppler frequency and the bit sign transition of the navigation message in a low SNR environment [2]. Figure 1 shows the functional structure of the IAADFC algorithm.

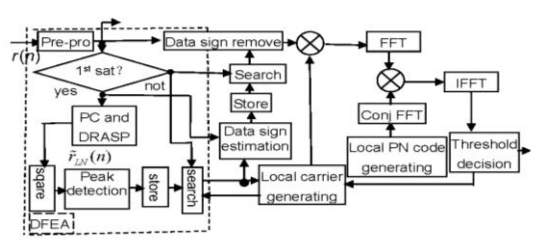


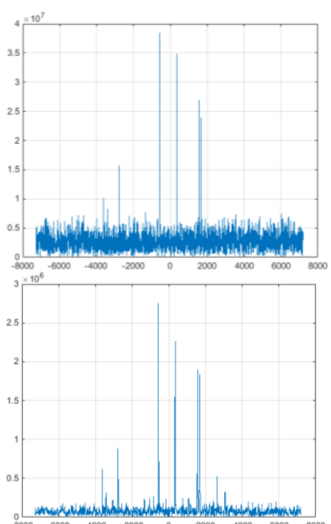
Figure 1.Function structure of IAADFC algorithm.

A. *IAADFC Algorithm*

The main idea of IAADFC algorithm[2] is that it can estimate the carrier Doppler frequency and the bit sign transition of the navigation message. Doppler Frequency Estimation Algorithm (DFEA) is designed to estimate the carrier Doppler frequency, which will be Analyzed first as follows.

DFEA algorithm proposed in our former papers can estimate the Doppler frequency[2,12]. The unknown PRN Code and navigation message data Bit are removed from the *Incoming GNSS Intermediate Frequency Signal* (IGIFS) via square operation after DBSP operation. Therefore, the result signal IGIFS only contains carrier signal and noise. When $\tilde{r}_{LN}(n)$ is converted to $\tilde{R}_{LN}(f)$ in frequency domain by FFT calculation, the frequency of each visible satellite signal can be easily to find through searching the maximum value in $\tilde{R}_{LN}(f)$. Obviously, the Doppler frequency can be estimated using DFEA.

Based on the theory of signal processing, Data Block Stacking Processing (DBSP) can increase signal amplitude and reduce noise amplitude. Therefore, *DFEA* algorithm can estimate the Doppler frequency under a low SNR environment. Some results $\tilde{R}_{LN}(f)$ obtained when SNR decrease by 12 dB are shown in Figure 2. It demonstrates that DBSP operation can increase the SNR of input signal. What is more, the longer the input data, the higher the SNR gain.



(a)20ms IGIFS data (b) 80ms IGIFS data

Figure 2. DFEA algorithm detection output.

AS shown in Figure 1, DFEA algorithm runs just before acquisition algorithm begins. After DFEA algorithm runs over, Doppler frequency estimation results are stored in the look-up Table Acqb where are totally 10~12 records. Therefore, DFEA algorithm does not significantly increase the complexity of IAADFC algorithm.

Data Bit Sign Transition (DBST) Estimation algorithm is designed in IAADFC algorithm to estimate the bit sign transition of the navigation message. The basic idea of data bit sign transition (DBST) estimation for a navigation message is described as follows.

Assume that the data length of IGIFS used in the DBST estimation is $T_I = (KL + t)$, where t is the time length of the data block, specifically, the number of PRN code periods in a data block. By selecting the T_I ms data, we can obtain（T_I-t+1）correlation results, which reflect the correlation between IGIFS and local signal. Because the data bit sign transition will lead the correlation reduced significantly. Therefore, we can get the serial number of data block where DBST occurs by searching the minimum value in (TI-t+1) correlation results. Therefore, the proposed DBST method[2] can detect DBST.

B. *The Analysis of the DBZP Algorithm*

The DBZP algorithm has difficulties in its application because it is limited by the large amount of data processing,. However, the DBZP algorithm is a well-accepted ideal solution for weak signal acquisition of an unaided satellite navigation receiver. Therefore, we compare the IAADFC algorithm with the DBZP algorithm in this paper, which shows that the IAADFC algorithm is superior to DBZP algorithm in both acquisition sensitivity and acquisition speed.

The concrete realization method of DBZP is a process of constructing a coherent integral matrix Mc. As shown in Table 1, the number of rows of matrix Mc is the number of blocks and the number of columns is the number of sampling points per millisecond. The energy of all the points of matrix Mc is calculated by a Fourier transformation for each column. If its maximum value is greater than the given acquisition threshold, the acquisition succeeds.

TABLE I. DBZP MATRIX MC

block（1,1）	block（1,2）	……	block（1,K）
block（2,1）	block（2,2）	……	block（2,K）
⋮	⋮	……	⋮
block（Nb,1）	block（Nb,2）	……	block（Nb,K）

After partitioning the data blocks, the data sampling rate $f_s^{'}$ decreases to the $\frac{1}{S_b}$ of the original sampling rate, the number of data points N' is the total number of blocks; i.e., N_b . The resolution of the carrier frequencies is:

$$\Delta f' = \frac{f_s^{'}}{N'} = \frac{f_s}{S_b N_b} = \frac{f_s}{N} = \Delta f = \frac{1}{T_I} \tag{1}$$

Thus, the resolution of the DBZP-based acquisition method is the same as the resolution of a general parallel search acquisition algorithm in the frequency domain.

In the DBZP algorithm, the number of Doppler frequency points to be searched is the same as the number of data blocks, which is proved in the following way from the point

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of view of frequency resolution. Beginning from the derivation of the above-mentioned carrier frequency resolution and assuming that the Doppler frequency search range is $(f_{\min}, f_{\max})$, the number of data blocks can be obtained by the following equation:

$$N_b = \frac{(f_{\max} - f_{\min})}{\Delta f} = (f_{\max} - f_{\min}) T_I \qquad (2)$$

Obviously, the value of the above equation is also equal to the number of Doppler frequency points to be searched.

The integrity of the PRN code is broken after partitioning the data blocks. Therefore, it needs a block-shift operation so that the PRN code and the IGIFS signal can be fully correlated. Since the PRN code has a periodicity, it is not necessary to perform the block-shift operation on all the blocks, it just required to performed on one period data. The number of blocks to be shifted for one period of the PRN code is:

$$N_{ms} = \frac{N_s}{S_b} = \frac{f_s}{1000} \frac{(f_{\max} - f_{\min})}{f_s} = \frac{(f_{\max} - f_{\min})}{1000} \qquad (3)$$

It can be seen that the number of blocks to be shifted is directly determined by the Doppler frequency search range. According to (3), the number of data points in one block can be deduced, which is:

$$S_b = \frac{f_s T_I}{N_b} = \frac{f_s T_I}{(f_{\max} - f_{\min}) T_I} = \frac{f_s}{(f_{\max} - f_{\min})} \qquad (4)$$

Note that the number of data points in one data block is determined by both the sampling rate and the Doppler frequency search range in the DBZP algorithm.

III. SIMULATION RESULTS

Simulation was done based on the GPS software receiver platform SoftGNSS V3.0[13], developed by Darius Plausinaitis and Dennis M. Akos. et al.. The detection strategy of their acquisition algorithm uses a maximum-to-second-maximum ratio (MTSMR). Therefore, we define the acquisition decision variable (ADV) as the ratio of the maximum value to the second maximum of the coherent integration output. We run the platform in a MATLAB 2014b programming environment.

The IGIFS used in our simulation comes from sampling data of a real GPS IF signal that was downloaded from an open web source. The input signal with different signal-to-noise ratio (SNR) is obtained by adding noise to the IF sampling data IGIFS in this paper. It is described as follows

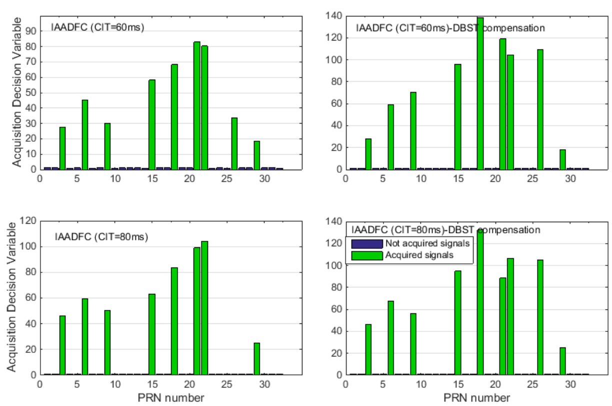
$$P_{sig} = \frac{sum(sig.*sig)}{length(sig)} \qquad \sigma_n^2 = \frac{P_{sig}}{10^{SNR/10}}$$
$$n_1 = randn(size(sig)) \qquad n_2 = n_1 - mean(n_1) \qquad (5)$$
$$n = \frac{\sigma_n}{std(n_2)} \cdot n_2 \qquad data_{IGIFS} = data_{IGIFS} + n$$

where sig is input signal IGIFS, P_{sig} is its power, σ_n^2 is the noise variance, its value is equal to the noise power, n is the noise vector that satisfies the SNR requirement.

In terms of the rapid acquisition of a weak signal, non-coherent integration (NCI) is preferred because of its low complexity. The DBZP algorithm is widely recognized in the field of weak-signal acquisition. Taking computational complexity and sensitivity as the measurements, eight typical satellite signal acquisition methods are analyzed [16], and the DBZP algorithm is considered to have the best acquisition performance in a weak-signal environment. For the above reasons, we will provide a detailed simulation and compare among the IAADFC algorithm, NCI algorithm and DBZP algorithm.

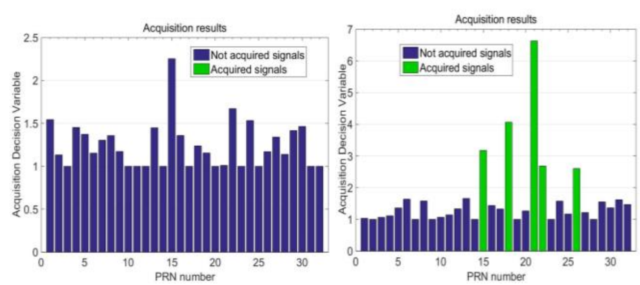
For IAADFC algorithm and NCI algorithm, some simulation and experimental results have been published in the Journal GPS Solutions, as detailed in the references Gao and Xia (2018). Only some improved simulation results, as well as analysis and comparison results are listed here.

The impact of DBST is remove from IGIFS data by multiplying the corresponding data by -1 after each DBST points. Then, the acquisition results after DBST correction are obtained, some of which are shown in Figure 3.



(a)ADV without DBST (b)ADV with DBST correcting

Figure 3. The impact of DBST correcting on IAADFC algorithm.



(a)ADV without DBST (b)ADV with DBST correcting

Figure 4. The impact of DBST correcting on DBZP algorithm.

Some acquisition results of DBZP algorithm about the affection of DBST correction are list in Figure 4. When noise is added to IGIFS data to reduce its SNR by 38 dB and the acquisition time is 60 milliseconds, the results without DBST correction are shown in the left panel and the results with DBST correction are shown in the right panel. After DBST correction, the DBZP algorithm captures the signals from five satellites. It can be seen that the impact of DBST to DBZP algorithm is obvious.

In order to illustrate that the increase of CIT can effectively improve the acquisition sensitivity of the IAADFC algorithm, we perform analysis after reducing the SNR of the signal IGIFS by 15dB. The results of this analysis are shown in the middle two panels of Figure 5. When the CIT is increased from 5ms to 10ms, the number of satellite signals that can be acquired rise from 4 to 6. Therefore, with the increase of CIT, the acquisition sensitivity of the IAADFC algorithm is improved.

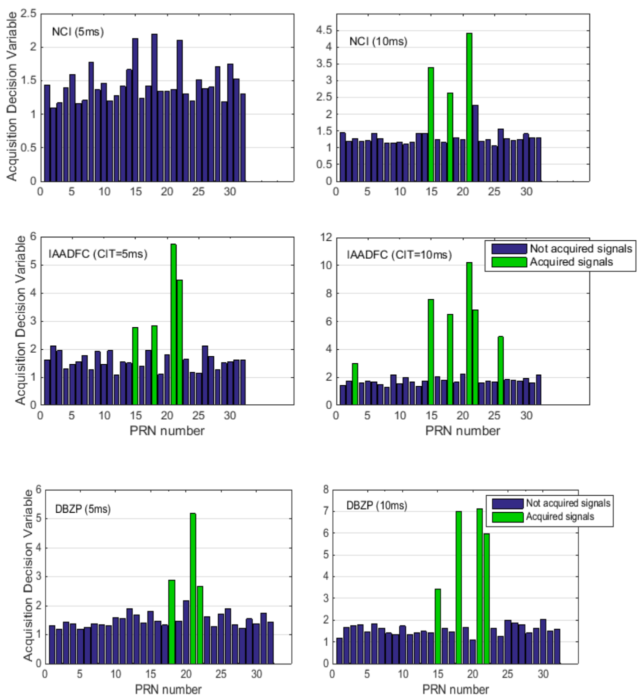


Figure 5. Comparison of IAADFC, NCI ,DBZP algorithms when SNR is reduced by 15dB.

Therefore, the IAADFC algorithm can achieve a higher sensitivity than the NCI algorithm or the DBZP algorithm. It can be seen that the acquisition sensitivity of the DBZP algorithm is lower than that of the IAADFC algorithm but it is higher than that of the NCI algorithm.

IV. CONCLUSION

In this paper, an IAADFC algorithm, a GNSS signal acquisition algorithm based on long-time coherent integration, is analyzed. GNSS signal acquisition at different SNR environments and different Doppler frequency estimation accuracy with different coherent integration time is simulated. It is found that in a weak signal environment, the IAADFC algorithm improves the acquisition sensitivity.

Based on the above simulation and analysis, if the Doppler frequency estimation accuracy of the DFEA algorithm is improved, it is found that in a weak signal environment, the IAADFC algorithm improves the acquisition sensitivity as compared to the DBZP algorithm, i.e, its acquisition sensitivity is higher than that of the DBZP algorithm.

Based on the above simulation results and discussion, conclusions can be drawn that the method of improving estimation capability of the navigation Data bit sign transition algorithm is worthy of further study. Therefore, we will devote to the research of DBST algorithm in the future.

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