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Signal Search and Acquisition Algorithms for Software GPS Receiver

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***Abstract*—Based on the software platform of MATLAB simula-tion, the paper collects the real GPS intermediate frequency (IF) signal by the IF signal sampler, and uses it to carry out the time-domain correlation acquisition and the fast Fourier transform (FFT) acquisition on the C/A code of GPS signal, and also carry out the decision of the single-binary search and the M/N search on the personal computer. The experimental results show that comparing to the algorithm of time-domain correlation acquisition, the algorithm of FFT acquisition can consumedly reduce the computing times, and accordingly reduce the acquisition time. In addition, comparing to the decision algorithm of single-binary search, the M/N search can consumedly reduce the false-alarm probability and improve the detection probability. So, the M/N search can both control acquisition time effectively and meet the high performance requirement of acquisition.**

***Index Terms*—software GPS receive, time-domain correlation acquisition, FFT acquisition, false-alarm probability, detection probability**

I. INTRODUCTION

In recent years, with the development of the technology of digital signal processing, the receiving and processing of GPS satellite signal more and more tends to use the software methods. And the software GPS receiver used by these methods is called as software GPS receiver. Compared to the traditional hardware GPS receiver, the software GPS receiver has the following specific advantages. It can upgrade easily and apply with new positioning methods. In addition, it is very flexible to process various frequency signals collected by hardware and can exploit and validate algorithms without changing hardware. As a result of the tremendous potential advantages of software GPS receiver, it is studied far and wide by a large number of agencies at home and abroad [1].

Based on the software platform of MATLAB simulation, the paper collects the real IF signal of GPS by the IF signal sampler to carry out the C/A code acquisition of GPS signal and the search and decision. The acquisition of GPS IF signal includes the time-domain correlation acquisition and the FFT acquisition, and the search algorithm includes the single-binary search and the M/N search.

II. GPS SIGNAL ACQUISITION PRINCIPLE

The C/A code of GPS signal is a typical signal of directsequence spread spectrum. And the de-spread of GPS receiver is set up on the basis of precise synchronization of PN code at two ends of transceiver [2]. The acquiring GPS signal is designed to estimate the pseudo-random(PN) code phase and Doppler shift of the received signal, then we use these estimated values to initialize the tracking loops. The acquisition methods mainly include the time-domain correlation acquisition [3] and the FFT acquisition [4].

A. Time-domain Correlation Acquisition

With the processing of down-conversion and A/D conv-ersion sampling, the GPS signal is changed to the digital IF signal of center frequency of ω_{IF}. And as a result of the relative motion of satellite and receiver, the frequency of IF signal is added with Doppler frequency of ω_d. Ignoring the data bit of navigation and noise, the GPS IF signal model is showed as follow:

$$s_k = Ac[(1+\eta)(t_k - t_s)]\cos[(\omega_{IF} + \omega_d)t_k + \phi] \quad (1)$$

Where A is the signal amplitude, t_s is the initial time of C/A code sequence, ϕ is the initial phase of carrier, $\eta = \omega_d / 2\pi \times 1575.42 \times 10^6$ is the Doppler shift caused by the disturbance of bit rate. After the low-pass filtering and accumulate and dump, there are two integral outputs of branch I and branch Q as follows:

$$I_k = \sum_{k=0}^{N-1} s_k c[(1+\hat{\eta})(t_k - \hat{t}_s)]\cos[(\omega_{IF} + \hat{\omega}_d)t_k] \quad (2)$$

$$Q_k = -\sum_{k=0}^{N-1} s_k c[(1+\hat{\eta})(t_k - \hat{t}_s)]\sin[(\omega_{IF} + \hat{\omega}_d)t_k] \quad (3)$$

Where N is the number of integral sampling point, generally speaking, the integral length is 1ms. Branch I and branch Q are merged into the following complex signal.

$$r(\hat{t}_s, \hat{\omega}_d) = \sum_{k=0}^{N-1} s_k c[(1+\hat{\eta})(t_k - \hat{t}_s)](\cos[(\omega_{IF} + \hat{\omega}_d)t_k] + j\sin[(\omega_{IF} + \hat{\omega}_d)t_k]) \quad (4)$$

The $r(\hat{t}_s, \hat{\omega}_d)$ can be considered as the cyclic correlation of $c[(1+\hat{\eta})(t_k - \hat{t}_s)]$ and $s_k(\cdot)$. The flow chart shown in Fig.1 is the principle of correlating acquisition in time-domain.

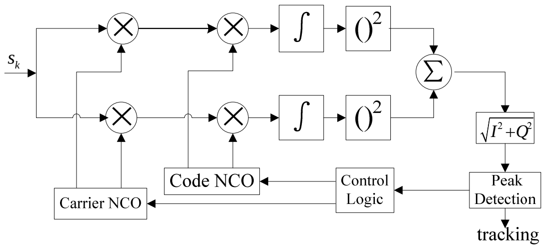


Figure 1. Block diagram of time-domain correlation acquisition

Where the search process of Doppler frequency and code phase is essentially the process of estimating and adjudicating the coefficient. The acquisition process is namely the two-dimensional search in the C/A code phase of $\hat{t}_s$ and Doppler frequency of $\hat{\omega}_d$ to detect the correlation value of $\sqrt{I_k^2+Q_k^2}$. And the signal acquisition is successful if the correlation value is higher than the threshold value.

B. FFT Acquisition

The operation of cyclic correlation in time-domain shown in (4) can be replaced by the Fourier transform in frequency domain. So all the correlating values can be calculated by the algorithm of FFT and IFFT simultaneously which is shown in the (5), (6) and (7) when $\hat{\omega}_d$ is fixed. As the frequency searching range of GPS signal is ± 10 kHz, and the search step is 1 kHz, the flowchart of FFT acquisition algorithm is shown in Fig. 2.

$$Y_i = FFT\left(s_i \left[\cos[(\omega_{IF} + \hat{\omega}_d)t_k] + j\sin[(\omega_{IF} + \hat{\omega}_d)t_k] \right] \right) \quad (5)$$

$$C_i = conj\left\{ FFT\left(c[(1+\hat{\eta})(t_k - \hat{t}_s)] \right) \right\} \quad (6)$$

$$r(i, \hat{\omega}_d) = IFFT([c_i Y_i]) \quad (7)$$

Where $i = 1, 2, \cdots, N-1$.

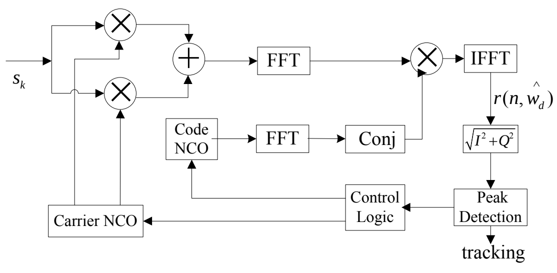


Figure 2. Block diagram of FFT acquisition algorithm

The searching process of FFT acquisition algorithm is shown as follows: Without the condition of priori value, the local carrier NCO aligns to the initial estimated value of frequency $\hat{\omega}_d$ to make the generated signal match one frequency searching unit. Then it starts the FFT acquisition loop to calculate the correlation values $r(\hat{t}_s, \hat{\omega}_d)$, and find out the maximum value with comparing all the correlation values. Finally, we compare the maximum value with the threshold. It indicates that the signal is acquired successfully obtaining the code phase and Doppler frequency of the signal location if the maximum value is greater than the threshold, which is the basis for signal tracking. Otherwise the signal is not acquired that is essential to change the Doppler searching unit with changing the control logic to do the above again.

III. SIGNAL SEARCH PRINCIPLE

In the section of GPS signal acquisition, the module of signal detection compares the correlated signal envelope with the threshold judging whether the signal is at the current search unit. As the signal is random, it is a binary decision in essence which phases into different search algorithms achieving different performances of signal detection. In addition, different search algorithms need different control logics while searching control logic is the key of signal acquisition. Hereinafter, based on the detection probability, detection probability and search rate of GPS signal, the paper analyses the acquisition performance to GPS signal [5].

A. Single-binary Search Algorithm

As both the $I(k)$ and $Q(k)$ in (2) and (3) act on Gaussian random distribution, the signal envelope $H(k)$ acts on the Rice distribution with the probability density showed as follow:

$$P_s(z) = \frac{z}{\sigma_n^2} \exp[-(z^2 + A^2)/2\sigma_n^2] I_0\left(\frac{zA}{\sigma_n^2}\right), z \geq 0 \quad (8)$$

Where z is a random variable which is equivalent to signal envelope; A is the signal amplitude, $I_0(\cdot)$ is the Bessel function of zero-order correction; and σ_n is the root mean square of noise power. The $P_s(z)$ shown in (8) can be expressed as the following SNR form of pre-detection.

$$P_s(z) = \frac{z}{\sigma_n^2} \exp[-\frac{z^2}{2\sigma_n^2} + \frac{s}{n})] I_0\left(z\frac{\sqrt{2s/n}}{\sigma_n}\right), z \geq 0 \quad (9)$$

Where $s/n = A^2/2\sigma_n^2 = (c/n_0)T$ and $S/N = \log(s/n) = C/N_0 + 10\log(T)$ (dB). C/N_0 is the density ratio of carrier-noise power, and T is the pre-detection integral time. When there is no signal (A=0), the signal envelope acts on the Rayleigh distribution, and its probability density is as follow:

$$P_n(z) = \frac{z}{\sigma_n^2} \exp[-\frac{z^2}{2\sigma_n^2}], z \geq 0 \quad (10)$$

If the searching process uses a single decision and $H(k) \geq V_t$, which indicates the signal is acquired successfully, or it is not failed. The false-alarm probability and detection probability of GPS signal can be expressed as follows:

$$\begin{aligned} P_{fa}(z) &= \int_{\sqrt{V_t}}^{\infty} p_n(z)dz = \exp(-V_t / 2\sigma_n^2) \\ P_d(z) &= \int_{\sqrt{V_t}}^{\infty} p_s(z)dz \end{aligned} \quad . \tag{11}$$

Where

$$V_t = -2\sigma_n^2 \ln P_{fa} \tag{12}$$

Assume σ_n =1(normalized), we can calculate out the threshold V_t according to P_{fa}, thereby we can also obtain different values of P_d with different SNR. The threshold selection is restricted by P_{fa} and P_d.

B. M/N Search Algorithm [6]

M/N searching is defined as doing N times decision to each searching unit, and if the signal envelope is higher than the set threshold with M times, then the signal acquisition succeeds; or it would continue to search next unit. The false-alarm probability and detection probability of this algorithm is the following:

$$\begin{aligned} P_{fa1} &= \sum_{n-M}^{N} C_N^n P_{fa}^n (1-P_{fa})^{N-n} \\ P_{d1} &= \sum_{n-M}^{N} C_N^n P_d^n (1-P_d)^{N-n} \end{aligned} \quad . \tag{13}$$

This algorithm can improve the detection probability and reduce false-alarm probability effectively. But it must increase the acquisition time of C/A code. So, it is a compromise between the acquisition time of C/A code and reducing false-alarm probability. And the size of M and N is selected within the specific requirement.

IV. EXPERIMENT ANALYZING

A. Experimental Platform Structure

For achieving the acquisition and search decision of GPS signal, the paper puts up the simulating platform [7] shown in Fig. 3. It gets the IF digital signal of GPS by the IF signal sampler of NewStar210 inputting to PC for achieving the acquisition and search decision of GPS signal and using to the latter tracking module.

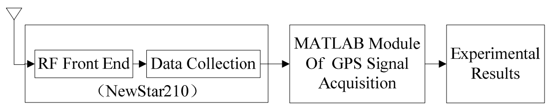
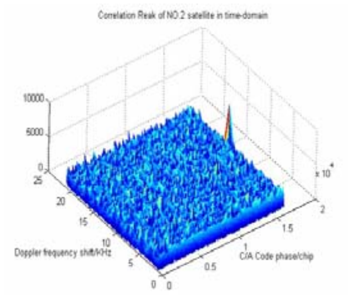


Figure 3. Block diagram of experimental platform

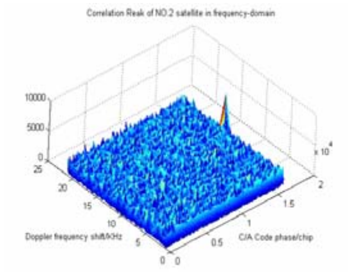
B. Comparison on GPS Signal Acquisition

The GPS satellite signal includes signal of all 32 satellites while the received signals are just the measured signals of visible satellites, so different satellite has different signal Doppler shift and initial code phase. On case of no transcend-dental information, the GPS receiver must search all of 32 satellites. The paper selects the visible satellite NO.2 to analyze the acquisition performance. The acquisition values of NO.2 satellite by time-domain correlation acquisition algorithm and FFT acquisition algorithm are shown in Fig. 4 (a) and (b) respectively.

Comparing the acquisition values shown in the two figures, the initial code phase and Doppler shift obtained by FFT acquisition are the same as those of time-domain correlation acquisition whose values are 16293 and 20492635 Hz respectively, while the correlation peak of these two acquisition algorithm are 8002.8734 and 7981.5316 respectively, which indicates that the signal acquisition accuracy of two algorithms are basically consistent with the same carrier Doppler searching step size.



(a) time-domain correlation acquisition



(b) FFT acquisition

Figure 4. Acquisition values of NO.2 satellite

However, the operation time of FFT acquisition is very different from the time-domain correlation acquisition. The experiment takes the data of 1ms as the length of acquisition (contained 16,367 sampling points) whose searching band-width of carrier Doppler is ±10 kHz, and the searching step size is 1 kHz. And the operation time of two acquisition algorithms are shown in table I. According to the Table. I on the same experimental environment, the operation time of time-domain correlation acquisition with single frequency point is 4.2723 seconds, while that of FFT acquisition is only 0.0792 seconds. In addition, on case of 21 frequency points, the operation time of time-domain correlation acquisition is 89.7179 seconds, while that of FFT acquisition is only 1.6625 seconds. So the operation time of time-domain correlation acquisition is very large, but the FFT acquisition can reduce the operation times greatly, and shorten the acquisition time. This is very helpful to improve the performance of GPS receiver.

TABLE I. COMPARISON OF OPRATION TIME

Acquisition algorithm	Operation time of 1 ms data	
	single frequency point	all 21 frequency points
time-domain correlation	4.2723	89.7179
FFT	0.0792	1.6625

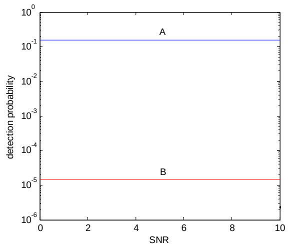
unit: second

C. Performance Analysis on Signal Search

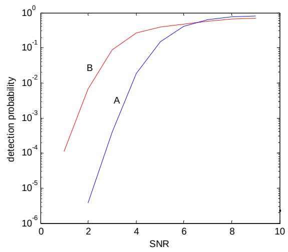
Assume the threshold is 1.92, σ_n=1, M=8 and N=10, we can obtain the false-alarm probability and detection probabi- lity of both single binary search algorithm and M/N search algorithm according to (11) and (13), which are shown in Fig. 5 (a) and (b) respectively.

According to Fig. 5 (a), the false-alarm probability of this algorithm is very high which is higher than 10^{-1} because of the single-binary search algorithm using single decision while the M/N search algorithm's is very low which is lower than 10^{-5}.

According to Fig. 5 (b), the detection probability of single-binary search algorithm is similar to that of M/N search algorithm with high SNR, which are both close to 1. And the detection probability of single-binary search algorithm reduces rapidly along the decreasing SNR, while that of M/N search algorithm just reduce slowly. In addition, the detection probability of single-binary search algorithm deteriorates seriously with the low SNR, and that of M/N search algorithm also reduces rapidly which is still higher than 10^{-4}.



(a) false-alarm probability



(b) detection probability

Figure 5. Distribution of false-alarm and detection probability

In summary, the M/N search algorithm can greatly reduce false-alarm probability and improve detection probability compared to single-binary search algorithm. According to the analysis on M/N search algorithm, the paper takes M=8 and N=10 while ensuring the acquisition performance, it also controls the acquisition time of C/A code effectively at the same time.

V. CONCLUSIONS

The paper studies the acquisition performance of GPS receiver on the MATLAB software platform which makes use of collecting GPS IF signal to achieve the time-domain correlation acquisition and FFT acquisition of C/A code and compares the algorithm performances of single-binary search with M/N search. The experimental results show that the FFT acquisition algorithm can greatly reduce the operation times and shorten the acquisition time compared to time-domain correlation acquisition algorithm. So it is more suitable to software GPS receiver on real time requirement. In addition, comparing to the single-binary search algorithm, the M/N search algorithm can ensure the acquisition performance and effectively control the acquisition time of C/A code at the same time.

The simulation platform discussed in the paper is based on the simulation platform of entire software GPS receiver. So the acquisition parameters obtained in the paper could be suitable for algorithm simulation and real-time study of comprehensive software GPS receiver such as signal tracking, bit synchronization, frame synchro- nization, message decoding and positioning analysis and so forth.

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