Chapter 31
Fast Recapture and Positioning Algorithm Based on PMF-FFT Structure

Xinpeng Yue, Haiyang Quan and Lidong Lan

Abstract GNSS signal acquisition is the most important process in a receiver followed by tracking and extraction of navigation bits. Partial Matching Filter (PMF) and Fast Fourier Transform (FFT) algorithm has advantages in acquisition speed and hardware complexity. In general, GNSS navigation data acquisition needs a common frame synchronization algorithm, which takes one sub-frame period of time for a determination. This means the receiver will take at least 6 s to reposition after the signal lost lock and recapture. In this paper, the design of PMF-FFT based receiver is described. A fast method of solving the long-time frame synchronization problems is proposed. The method uses the α-β filter algorithm to correct local time and estimate signal sending time. Experimental results show that the proposed methods for the PMF-FFT based receiver are able to perform faster and reliable acquisition and reposition.

Keywords GNSS · PMF-FFT · Recapture · GPS · Compass-2

31.1 Introduction

Global Navigation Satellite System (GNSS) is a satellite-based radio navigation system, such as GPS, COMPASS-2, and GALILEO and so on. It has been widely used in both military and civilian community for navigation, location, timing, and other related applications. In this paper, we mainly study on the GPS and COMPASS-2 satellite system. The satellite navigation receivers capture the RF modulated signals, down convert them to an intermediate frequency (IF), digitize them,

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and perform signal processing to extract the position information from the navigation message.

Signal acquisition is the first step of signal process and the most important process in a GNSS receiver followed by tracking and extraction of navigation bits. Performing faster and reliable acquisition and having lower hardware complexity are very important to the receiver. PMF-FFT algorithm [1, 2] is a parallel acquisition algorithm. It has higher speed than two dimensional serial acquisition algorithms [3] and lower hardware complexity than FFT based time-domain parallel acquisition algorithm [2, 4]. We designed PMF-FFT structure and build the relevant receiver. After signal reacquisition, the receiver performs tracking, bit synchronization, frame synchronization and position processes. However, among all processes frame synchronization takes longer [2]. So, how to shorten the frame synchronization time is the most important method to decrease the position time and improve receiver performance.

31.2 The GPS Navigation Message and Frame Synchronization

The GPS and COMPASS-2 system have the similar signal structure. We will mainly introduce the GPS system. The signal is made of carrier, C/A code, and navigation message data. Each GPS satellite (or transmitter) has a unique C/A code (spreading gold code) that is orthogonal to all the other satellites' codes. GPS receivers, on the other hand, must search for these C/A codes to know which satellites are available to the user. For each code, a receiver must perform a 2-D search for carrier frequency offset and code shift, or in other words acquire the C/A code. Then it should track (or lock in) the signal and extract navigation messages. Navigation messages stream be transmitted by the satellite on the L1 carrier frequency of 1575.42 MHz at a rate of 50 bps. The message structure shall utilize a basic format of a 1500 bit long frame made up of five subframes, each subframe being 300 bits long. Subframes four and five shall be subcommutated 25 times each, so that a complete data message shall require the transmission of 25 full frames. Each subframe shall consist of ten words, each 30 bits long; the MSB of all words shall be transmitted first. Each subframe and/or page of a subframe shall contain a telemetry (TLM) word and a handover word (HOW), both of which are generated by the satellite, and shall start with the TLM/HOW pair.

The TLM word shall be transmitted first, immediately followed by the HOW. The HOW shall be followed by eight data words. Each word in each frame shall contain parity. Each TLM word is 30 bits long, occurs every 6 s in the data frame, and is the first word in each subframe/page. Each TLM word shall begin with a preamble, which is used to frame synchronization. After, extracting navigation messages from the signal, the receiver don't know where the starter is. Frame synchronization process can find the preamble 10001011 to confirm the starter of a subframe and then start to extract navigation message and the satellite signal sending time.

31.3 Analysis of PMF-FFT Algorithm and Receiver

Partial Matching Filter will divide T_{coh}(a prediction integration time, PIT) into P portion, then every segment data $T_p = T_{coh}/P$, and every segment has C/A code chips $X = 1023^* T_P$. If P = 1, the Partial Matching Filter become the Full Matching Filter, or in other words serial acquisition algorithm. Usually receiver chooses 1 ms (period of C/A code) signal to acquire. All sample points are first filled with several zeros (first zero filling) and cut into P parts, and each part has X points. Then receiver produces local C/A code and make the same partition, M is the number of T_{coh} between the local C/A code and the GPS C/A code. Then both signal and C/A codes are at the same time sent into PMF in which average correlation operation is made. The outputs Q are filled with several zeros (Q to N) to meet the requirement of 2-based FFT and then do the FFT. Figure 31.1, show the structure of PMF-FFT algorithm.

The GPS signal can be expressed as:

$$S_i = \sqrt{A} D_{(t)} C_{(t-\tau)} \cos(\omega_0 t + \omega_d t + \varphi) + n_{(t)} \tag{31.1}$$

where A is the amplitude of signal; $D_{(t)}$ is navigation date code each element of which has a breadth of 20 ms; $C_{(t-\tau)}$ is pseudo-random code (C/A code) with a period of 1 ms and 1023 code elements in each period; ω_0 is medial frequency; ω_d is Doppler frequency; Φ is carrier phase; n is gauss noise.

The PMF filters perform correlation operation with receiving signal and generating L1 C/A code. Here, $R_{(\tau)}$ is the C/A code self-correlation the output of the n-th parts in the PIT time can be expressed as [5, 6]:

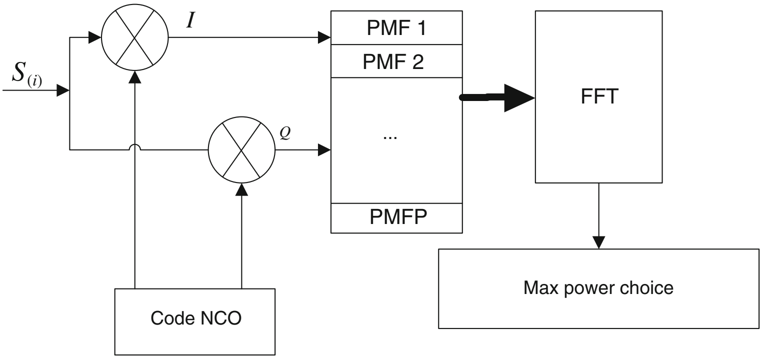

Fig. 31.1 The structure of PMF-FFT

$$Q_{(n)} = \frac{\sqrt{2A}}{2} R_{(\tau)} \frac{\sin(\pi f_d T_P)}{\sin(\pi f_d T_S)} \sin\left(n w_d T_P + \varphi\right) + N_{Q(n)} \quad \mathrm{n} = 0\ldots\mathrm{p} - 1 \tag{31.2}$$

$$I_{(n)} = \frac{\sqrt{2A}}{2} R_{(\tau)} \frac{\sin(\pi f_d T_P)}{\sin(\pi f_d T_S)} \cos\left(n w_d T_P + \varphi\right) + N_{Q(n)} \quad \mathrm{n} = 0\ldots\mathrm{p} - 1 \tag{31.3}$$

Combining $Q_{(n)}$ and $I_{(n)}$ as $I_{(n)} + j^{*} Q_{(n)}$ and then performing FFT by zero filling, the outputs can be expressed real part and image part as:

$$Q_{(k)} = \frac{\sqrt{2A}}{2} R_{(\tau)} \sin\psi \frac{\sin(\pi f_d T_P)\sin(\pi f_d T_P - k\pi P/N)}{\sin(\pi f_d T_S)\sin(\pi f_d T_P - k\pi/N)} + N_{Q(k)} \quad \mathrm{k} = 0\ldots\mathrm{N} - 1 \tag{31.4}$$

$$I_{(k)} = \frac{\sqrt{2A}}{2} R_{(\tau)} \cos\psi \frac{\sin(\pi f_d T_P)\sin(\pi f_d T_P - k\pi P/N)}{\sin(\pi f_d T_S)\sin(\pi f_d T_P - k\pi/N)} + N_{Q(k)} \quad \mathrm{k} = 0\ldots\mathrm{N} - 1 \tag{31.5}$$

Here, $\psi = \varphi + (\omega_d T_P / T_s - 2\pi k/N)(N - 1)$.

The GNSS receiver based on PMF-FFT structure is designed to acquiring, tracking and positioning. The GNSS receiver we designed can implement the GPS, COMPASS-II and GPS + COMPASS-II navigation. There are mainly two parts of the receiver: RF part and digital process part. The RF part converts the radio frequency signal to a lower frequency and then digital process part perform acquiring, tracking and positioning process to output the results. In the designed receiver, we choose intermediate frequency of 4.092 MHZ and sampling frequency of 16.38 MHZ. Figure 31.2 shows the prototype broad of real receiver.

31.4 Faster Positioning Methods

In the GNSS receiver, the most important information is the navigation messages sending time and transforming time (or pseudo-range). The final aim of

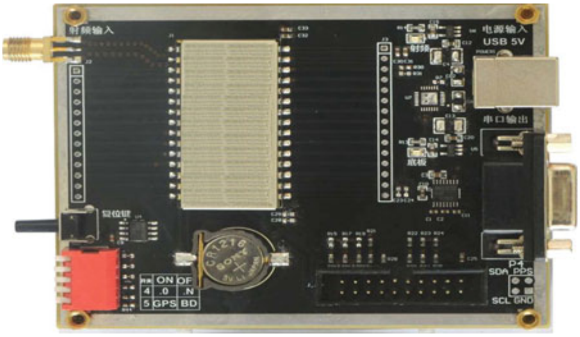

Fig. 31.2 Prototype broad of real receiver

acquisition, tracking and extracting of data is about to getting the navigation messages sending time and transforming time. The performance and capability of the receiver is mainly about the precision of time. The calculation of messages sending time can be expressed as:

$$t^{(s)} = TOW + (30^{*}w + b)^{*}0.02 + \left(c + \frac{CP}{1023}\right)^{*}0.001 \tag{31.6}$$

where TOW is the 17 MSBs of the time-of-week count; w is the count of word which start from the prompt subframe, as we introduce in Sect. 31.2, Each subframe shall consist of ten words, each 30 bits; b is count of bits, each 20 ms width; c is cycle count of C/A code with a period of 1 ms and 1023 code elements in each period; CP is C/A code phase which mainly decide the accurate of pseudo-range. Pseudo-range is defined as below:

$$\rho = r + c * (\delta t_u - \delta t^{(s)}) + I + T + \varepsilon_p = r + c * (\delta t_u - \delta t^{(s)}) + \varepsilon \tag{31.7}$$

where t_u is receiver's time; $t^{(s)}$ is message sending time; c stands for the speed of light; r is the range between receiver and satellite; δt_u and $\delta t^{(s)}$ is the clock deviation of receiver's clock and satellite clock; I stands for ionospheric delay; T stands for troposphere delay; ε_p is measure deviation; ε is called estimation deviation, which is of the accumulation of I, T, ε_p. As we analyze the message sending time composing before, considering the ε can be neglectable, compared with cycle count of C/A code. The most important factor is how to get the accurate bits count and C/A code cycle count.

The pseudo-range is mainly decided by the distance between satellite and user. We can estimate the movement of pseudo-range. As Fig. 31.3 shows earth radius R_e is 6,368 km, the distance R_s is 26560 km. The satellite orbits the earth every 12 h. We suppose the satellite is traveling at constant velocity, so we can calculate his angular speed $\frac{d\theta}{dt} \approx \frac{2\pi}{12*3600} = 1.454 * 10^{-14}$ [rad/s] and cutting speed $v_s = R_s \frac{d\theta}{dt} \approx 3862$ [m/s]. From the geometry principle, we can get expression of v_d as:

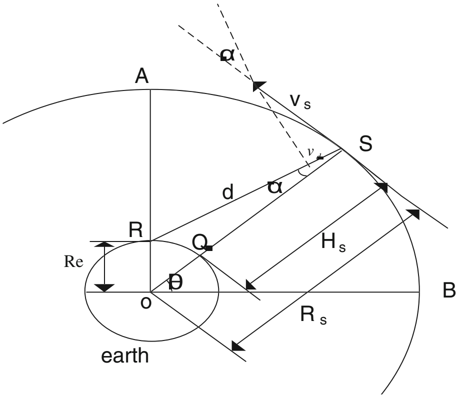

Fig. 31.3 Model of satellite orbit

$v_d = \frac{v_s R_e \cos\theta}{\sqrt{R_e^2 + R_s^2 - 2R_e R_s \sin\theta}}$. Assuming $\frac{dv_d}{d\theta}$ is zero, the maximum value $v_{dm} = v_s \frac{R_e}{R_s} = 925.9$ [m/s]. The rate of v_d is $\frac{dv_d}{dt} = \frac{dv_d}{d\theta}\frac{d\theta}{dt}$, we can easily find that when $\theta = 90^{\circ}$, the $\frac{dv_d}{d\theta}$ and $\frac{dv_d}{dt}$ have the max absolute value, so we can get the max absolute value of $\frac{dv_d}{dt} = 0.177$ m/s^2.

The analysis shows us that there is a very small acceleration in the direction between receiver and satellites. In other words, the velocity rate is smooth. Therefore, we can estimate the distance between satellites and receiver using the having information with α-β filter after the signal lost and recapturing, realizing faster positioning. The faster position α-β method can be described as:

$$\begin{cases} x_k = (1-\alpha)x_a + \alpha x_b \\ v_k = (1-\alpha)v_a + \alpha v_b \\ x_a = (1-\beta)x_{k-1} + \beta v_{k-1} t \\ v_a = (1-\beta)v_{k-1} + \frac{\beta}{t}(x_k - x_a) \end{cases} \tag{31.8}$$

x_k is filtered distance; x_a is estimated distance; x_b is measured distance; x_{k-1} is last recorded distance. v_k is filtered velocity; v_a is estimated velocity; v_b is measured velocity; v_{k-1} is last recorded velocity .

In the receiver soft design, the receiver records the bits count and ms count before signal lost, and refreshes the satellite data sending time with the receiver count, so we can quickly obtain the massage sending time after the signal tracking again without frame synchronization. When tracking again, we import measuring sending time and estimating sending time to α-β filter, so we can get more precise signal transforming time and achieve more precise position. Compared with others, such as frame synchronization method [7, 8], this method can also achieve faster reposition after tracking again and reduce the calculations, in other words,

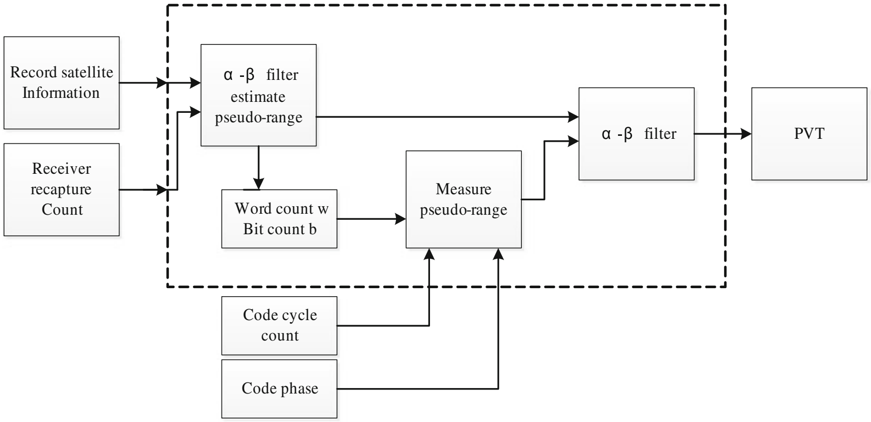

Fig. 31.4 Flow chart of fast synchronization and accurate reposition

Table 31.1 Comparision of two test channel

Number of experiments	1st		2nd		3rd		4th	
Channel	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Estimated pseudo-range(s)	0.07483608	0.07483548	0.07941842	0.07941863	0.07268464	0.07268504	0.08116371	0.08116353
Pseudo-range(s)	0.07483534	0.07483534	0.07940885	0.07940885	0.07268527	0.07268527	0.08116398	0.08116398
Word count w	6	6	7	7	8	8	5	5
Bit count b	5	5	0	0	27	27	18	18
Reception time(s)	0.8		0.85		0.89		1.2	

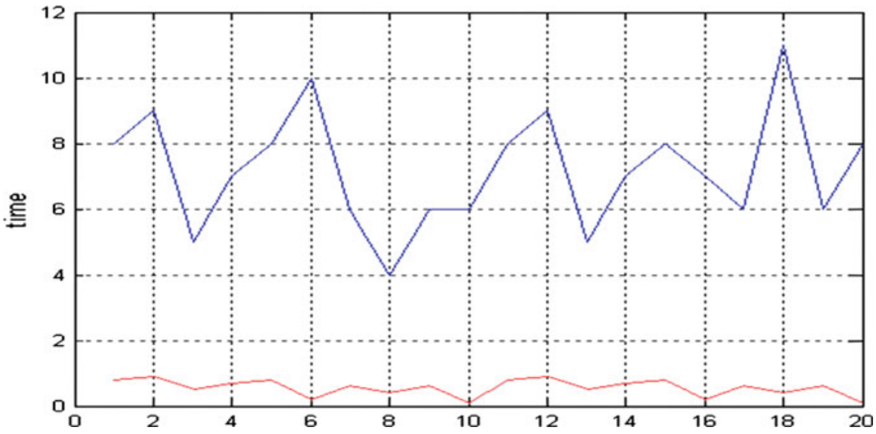

Fig. 31.5 Time consumption of reposition

the hardware time cost can be lower. Figure 31.4 is the flow chart of fast frame synchronization and accurate reposition.

31.5 Experiment Results

To test and verify the correctness, effectiveness and practicality, we mainly carried out two sets of experiments on our receiver. The experimental L1 signal is from Spirent signal hardware simulator GSS8000 and real satellite.

Fig. 31.6 Outfield experiment

31.5.1 The Correctness Verification

In the experiments, we choose two tracking channel to track the same satellite, one as the reference channel, the other as the test channel. First, let the two channels track the prn7 satellite, then channel 1 starts to recapture the signal, and we read the output data, repeating four times. The results are shown in the Table 31.1.

Estimate pseudo-range is the α-β filter estimated pseudo-range. Pseudo-range stands for the receiver measured pseudo-range. The experimental results of the Table 31.1 show that channel 1 gets the same w and b with channel 2 witch is reference channel, computed from estimated pseudo-range, and verify the correctness of proposing method.

31.5.2 The Rapidity of Reposition

Figure 31.5 shows the time consumption of reposition after tracking again. The blue is consumption of the normal position method which needs 6 s to frame synchronization [2]. The red is the consumption of proposing method. The normal position method consumes longer time than the proposed method, which takes no more than one second.

31.5.3 The Practicality Verification

The proposed method can make sure the continuous trajectory after the receiver through the overpass. This experiment was taken in South Four Ring Road, in Beijing. Figure 31.6 shows the output of outfield experiment.

31.6 Conclusion

In this paper, the PMF-FFT algorithm has been introduced and based receiver has been described. The α-β filter based algorithm has been used to reduce the time consumption of frame synchronization. The result shows that the PMF-FFT structure has a faster acquisition speed and the receiver can perform an accurate position after tracking again. In the common scene, the receiver can have a good performance and make sure the continuum of position. There are some problems in the proposed method, for example, the time of signal losing has been limited. So, in the future work, we will concentrate on this and other adding method.

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