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Direct GPS P-Code Acquisition Method Based on FFT

LI Hong (李 洪), LU Mingquan (陆明泉), FENG Zhenming (冯振明)**

Department of Electronic Engineering, Tsinghua University, Beijing 100084, China

Abstract: Recently, direct acquisition of GPS P-code has received considerable attention to enhance the anti-jamming and anti-spoofing capabilities of GPS receivers. This paper describes a P-code acquisition method that uses block searches with large-scale FFT to search code phases and carrier frequency offsets in parallel. To limit memory use, especially when implemented in hardware, only the largest correlation result with its position information was preserved after searching a block of resolution cells in both the time and frequency domains. A second search was used to solve the code phase slip problem induced by the code frequency offset. Simulation results demonstrate that the probability of detection is above 0.99 for carrier-to-noise density ratios in excess of 40 dB·Hz when the predetection integration time is 0.8 ms and 6 non-coherent integrations are used in the analysis.

Key words: GPS P-code; code frequency offset; maximum correlation result; direct acquisition; fast Fourier transform (FFT)

Introduction

In global positioning systems (GPS), the conventional acquisition of the precision code (P-code) relies on the hand-over from the corresponding coarse acquisition code (C/A code). Because the C/A code period is short (1 ms) and its chip rate is low (1.023 Mchip/s), even in the worst case the search amount is finite. Therefore, the C/A code acquisition is easy and fast. Since the P-code is synchronized with the corresponding C/A code, the P-code can be easily acquired with the aid of the C/A code. However, if the initial time uncertainty is not reduced through other methods, for instance with the aid of the C/A code, a direct search of the P-code chip-by-chip is very difficult due to its long period (1 week) and high chip rate (10.23 Mchip/s). Nevertheless, direct P-code acquisition does offer significant advantages. The P-code offers higher tolerance to jamming and spoofing than the C/A code. If the C/A code is disabled or unavailable, direct P-code acquisition will be the only choice. The higher chip rates present more opportunities to completely resolve distinct propagation paths in indoor/obstructed environments[1]. Diversity gains can be improved with multiple cell detection approaches.

Designers have developed several methods to directly acquire P-codes[1-12]. The STS Y-EXPRESS[3] employs a number of physical correlators and is capable of searching 511 resolution cells in parallel. Fast Fourier transform (FFT) methods are then used to correlate the results[4]. The extended replica folding acquisition search technique (XFAST) is one of the most effective methods[5,6]. The search can be accelerated by adding several blocks of local code replica together, but this adds extra noise to the correlation results and the acquisition performance deteriorates for weak signals. Directly averaging the incoming signal and the local code replica separately has the same advantages and disadvantages as XFAST and can be implemented using 1024-point FFT and inverse FFT (IFFT)[7]. An

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** To whom correspondence should be addressed.
E-mail: fzm@sdp.ee.tsinghua.edu.cn; Tel: 86-10-62784074

electro-optic correlator can be used to perform large-scale correlations at extremely high rates, but the signal processing loss is much greater than with digital signal processing[8].

The method presented here does not use folding or averaging so as to acquire a very long P-code with a low carrier-to-noise density ratio (C/N_0). The method uses the block processing technique to search code phases and frequency offsets in parallel. Large-scale FFT is used for the block processing. Only the maximum correlation result is saved after searching a block of code phases and carrier frequencies, which reduces the random-access memory (RAM) use. If the incoming signal matches the local code replica, the P-code phase of the incoming signal is declared. However, even with a very fast process, the receiver cannot acquire a real-time code phase due to the P-N code slipping induced by code frequency offset. A second search was developed to solve this problem.

1 Method

1.1 Acquisition method

Since the signal propagation time from a GPS satellite to a receiver is unknown, the exact code phase of the P-code cannot be identified. Since the carrier frequency offset reduces the correlation between the incoming signal and the local code replica, the total uncertainty region to be searched is two dimensional, in the time and frequency domains. The time-frequency uncertainty region can be discretized into a finite number of resolution cells. Typically, the time space is 1/2 of the P-code and the frequency space is proportional to the reciprocal of the predetection integration time (PIT).

Due to the long period and high chip rate of the P-code, the search region is often very large; therefore, conventional search algorithms which test one resolution cell at a time are too slow to search the P-code. Block searches which simultaneously search many resolution cells in time and frequency domains are, therefore, used. When the block search window aligns with the incoming signal and the input carrier-to-noise density ratio is high, the signal is immediately acquired. When the uncertainty region is large, not all the resolution cells can be covered at once and multiple blocks are used. For weak signals, the PIT cannot be extended indefinitely due to Doppler frequency effects and GPS data limitations. Therefore, non-coherent integration is often employed.

Figure 1 shows the direct P-code acquisition procedure in the baseband[1,4,9]. The signal received by the antenna is filtered, amplified, and down-converted to an intermediate frequency (IF). The A/D convertor digitizes the incoming signal and provides the samples for the baseband processing. The samples of incoming signal are saved for quasi real-time processing. Frequency domain processing techniques offer various advantages in GPS signal processing.

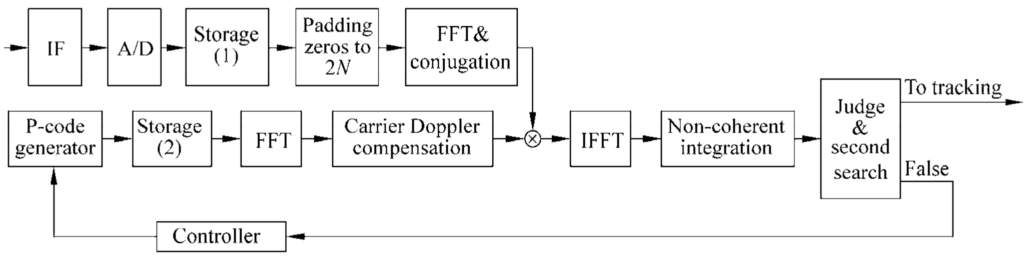

Fig. 1 Direct P-code acquisition block diagram

1.2 Correlation and FFT

For the FFT, denote $r(n)$, $l(n)$, and $y(m)$ as the incoming signal, the local code replica, and the correlation result, respectively.

$$y(m)=\sum_{n=1}^{N} l(m+n)r(n) \tag{1}$$

where N is the correlation length.

$Y(k)$, $R(k)$, and $L(k)$ are the FFT results for $r(n)$, $l(n)$, and $y(n)$. The symbol $\otimes$ represents circular convolution. The correlation can be computed simultaneously by the FFT[4].

$$y(n)=r(n)\otimes l(n) \Leftrightarrow Y(k)=R(k)L(k) \tag{2}$$

The N incoming samples are expanded to $2N$ points with zeros[1,9]. The data and the local code replica of length $2N$ are then separately transformed using the