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A New Approach for Pulsed Pseudolite Signal Acquisition Using FFT

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Abstract

This paper investigates the acquisition of pulsed pseudolite signal. We present the model of pulsed pseudolite signal. Based on a specific pulse pattern, performance of the serial pulse acquisition method is analyzed, and it's indicated that the prime disadvantage of this method is the long acquisition time. To solve this, we propose a new pulse acquisition method using FFT, and the model of this method is given. Then we focus on the segmentation question and the pulse truncation question in FFT acquisition method. Software simulation indicates that short segment length and pulse truncation detecting algorithm can effectively improve the performance of FFT pulse acquisition method.

1. Introductions

Pseudolite is a kind of ground based pseudo satellite transmitter, which transmit ranging signals similar to navigation satellite signals. Pseudolites have wide applications. They can initialize carrier-phase differential GPS navigation system to perform real-time dynamic positioning, and also can form unaided navigation network offering indoor navigation.

The primary problem of pseudolite application is near-far problem. To solve near-far problem, GPS employs the pulsed transmission technology, in which pseudolite signals are transmitted in frequent, short, strong pulses, as described in [1]. And the future Galileo system also tends to employ it.

To receive pulsed pseudolite signals, H.S.Cobb presented so called "saturated receiving method" in [2]. This method can effectively track pseudolite signals whose SNR are positive and higher than other signals, but in pseudolite network, because of interference between different pseudolite signals, saturated receiving method will not work well. And so far, there are few papers which discuss the receiving method of pulsed pseudolite signal.

In this paper, we propose a new pulsed pseudolite signal acquisition method using FFT, and also investigate detailed algorithms of this method.

2. Pulsed pseudolite signals

A pulsed pseudolite transmits signals in specific time slots, out of these time slots, it keeps electromagnetism silent. And the time slots of pulsed signals are generally generated according to some pulse pattern, have the pseudo-random property.

For Galileo E5 signal described in [3], one can generate pulse pseudolite signal according to the following method.

Generate pulse pattern by 7 bit LFSR, and divide a primary code period of E5 signal (10230 chips) into $2^7 = 128$ time slots. Pulsed signals are transmitted according to this pulse pattern, and there is only 1 pulse in 1ms. So the pulse duty cycle of this pulsed signal (PDC) is approximately 0.8%. An example of this pulsed signal is shown in Figure 1.

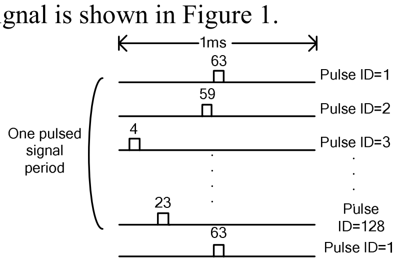


Figure 1. Example of pulsed pseudolite signal

To receive a pulsed signal described above, the receiver should confirm which pseudolite the pulse comes from (pseudolite ID), and what number of the pulse is in the pulse pattern (pulse ID).

Pulsed pseudolite signal can be described as:

$$s(t) = \sum_{i}^{P} \sum_{k=0}^{M-1} A \cdot D(i) \cdot C(i,k) \cdot g(i,k,t) \cdot \cos(\omega_c t + \phi_i) \qquad (1)$$

where, A is the amplitude of signal, $D(i)$ is navigation message, $\{C(i,k)\,|\,0 \le k \le M-1\}$ is ranging code in the i th pulse, $g(i,k,t) = g(t - [\sum_{j=0}^{i-1} T_p(j)] - kT_c)$, $g(t)$ is standard pulse waveform, T_c is chip width, $T_p(j)$ is time interval between the j th and $j-1$ pulse , which is controlled by the pulse pattern, P is the number of pulses in a pulse period, M is the number of code chips in a pulse. $L = P \cdot M$ is the number of code chips in a pulse period.

3. Serial acquisition of pulsed signals

The basic method of pulsed signal acquisition is serial acquisition method.

According to Eq.(1), the received signal for pulse ID=i at sampling time m can be described as

$$s_i(mT_s) = A' \cdot D(i) \cdot C(i, mT_s - \tau_i)\cos[(\omega_{IF} + \omega_d)mT_s + \phi_i'] \tag{2}$$

where, T_s is sampling interval, A' is the amplitude, ϕ_i' is the carrier phase, τ_i is the delay of received signal, ω_d is doppler frequency.

Suppose integration time is T_{ID} , the output of integrate-dump circuit at sampling time m is

$$\begin{aligned} I(m) &= \sum_{m=0}^{N-1} s(m) \cdot C(t_m - \hat{t}_s) \cdot 2\cos[(\omega_{IF} + \hat{\omega}_d)t_m] \\ &= \frac{1}{N}\sum_{k=(m-1)N}^{mN-1} 2A' \cdot D(i) \cdot R(\varepsilon T_c)\cos\Phi \cdot \cos\hat{\Phi} \end{aligned} \tag{3}$$

$$\begin{aligned} Q(m) &= -\sum_{m=0}^{N-1} s(m) \cdot C(t_m - \hat{t}_s) \cdot 2\sin[(\omega_{IF} + \hat{\omega}_d)t_m] \\ &= \frac{1}{N}\sum_{k=(m-1)N}^{mN-1} (-2A') \cdot D(i) \cdot R(\varepsilon T_c)\cos\Phi \cdot \sin\hat{\Phi} \end{aligned} \tag{4}$$

where, $I(m)$ and $Q(m)$ are respectively the inphase and quadrature channel output, $N = T_{ID}/T_s$, t_s is the initial time of ranging code, $\hat{x}$ is the estimated value of x , ε is the alignment error coefficient of received signal and local code, $\Phi = (\omega_{IF} + \omega_d)kT_s + \phi_i'$, $\hat{\Phi} = (\omega_{IF} + \hat{\omega}_d)kT_s + \hat{\phi}_i'$, $R(\cdot)$ is partial correlation of truncated ranging code. For pulsed signal shown in Figure 1, the period of $R(\cdot)$ is 128ms.

Suppose single dwell time is τ_D , acquisition probability is P_d , false alarm probability is P_{fa} , false alarm penalty coefficient is K , we can derive the mean acquisition time of serial acquisition that employs single dwell, by using the theory in [4].

$$\overline{T}_{serial} \approx \frac{64L \cdot (2 - P_d) \cdot (1 + KP_{fa})}{P_d} \cdot \tau_D \tag{5}$$

Eq.(5) indicates that the acquisition time of the serial acquisition method is very large

4. Acquisition of pulsed signals using FFT

To reduce the mean acquisition time, based on the FFT correlation theory, we propose a new pulsed pseudolite signal acquisition method using FFT.

Combining Eq.(3) and Eq.(4), the complex form of them is

$$\begin{aligned} r(n, \hat{\omega}_d) &= r(t_0 + n \cdot T_s, \hat{\omega}_d) = I(m) + jQ(m) \\ &= \sum_{m=0}^{N-1} s_m c_{m-n} \exp[-j(\omega_{IF} + \hat{\omega}_d)t_m] \\ &= IFFT[Y(M) \cdot C^*(M)] \end{aligned} \tag{6}$$

Where,

$s_m = 2 \cdot s(m)$, $c_{m-n} = C(m-n)T_s$,

$Y(M) = FFT\{s_m \cdot \exp[-j(\omega_{IF} + \hat{\omega}_d)t_m]\}$,

$C^*(M) = FFT(c^*_{m-n})$, x^* is the conjugate of x , n stands for the initial phase of ranging code. Therefore, the FFT correlation theory can be applied to pulsed pseudolite signal acquisition.

The major fraction of the block diagram of pulsed pseudolite signal acquisition using FFT is shown in Figure 2.

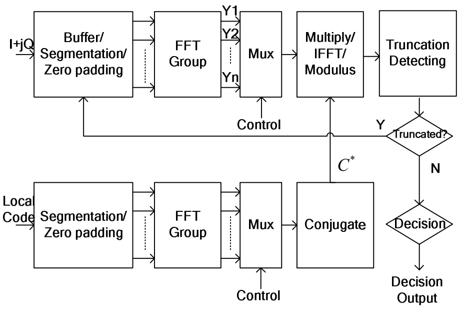


Figure 2. Block diagram of pulsed signal acquisition using FFT

Use FFT based method to search all searching area, the calculation process can be summarized as:

1) Buffer the down converted signal, segment according to specific segment length, pad zeros, and do FFT, denote the results as $\{Y_k\}$.

2) segment the local code according to specific segment length, pad zeros, do FFT, denote the results as $\{C_l^*\}$.

3) Do IFFT to $\{Y_k \cdot C_l^*\}$, set appropriate threshold as V_T . If $IFFT(Y_k \cdot C_l^*) \ge V_T$, it means the k th segment contains pulsed signal, and l denotes the pulse ID of received pulsed signal.

4) The truncation detection module can detect the truncation, and control the adjustment of segmentation.

Once the acquisition of l th pulse is finished, the receiver can correctly confirm time slots of the next incoming pulses according to the pulse pattern.

If a FFT transformer process r chips one time, suppose processing time is τ_{FFT}, the mean acquisition time of pulsed signal acquisition method using FFT is

$$\overline{T}_{FFT} \approx \frac{(2-P_d)(KP_{fa}+1)}{2P_d \cdot r} \cdot L \cdot \tau_{FFT} \quad (7)$$

Comparing $\overline{T}_{FFT}$ with $\overline{T}_{serial}$, by keeping the acquisition probability and false alarm probability the same, we get

$$\frac{\overline{T}_{FFT}}{\overline{T}_{serial}} = \frac{\tau_{FFT}}{128 \cdot r \cdot \tau_D} \quad (8)$$

From Eq.(8) we can see the mean acquisition time of FFT method reduces significantly.

5. Detailed algorithms

Different from continuous wave, there are some special problems to use FFT based pulsed signal acquisition method. The typical problems of them are segment length problem and pulse truncation problem.

5.1. Segment Length Problem

From above analysis, we can see that the segment length affects parameter r and τ_{FFT}. By decreasing segment length, r and τ_{FFT} will decrease at almost the same speed, so the change of segment length almost doesn't impact $\overline{T}_{FFT}$. But since the calculation complexity of FFT is $O(N \cdot \log_2 N)$, where N is FFT points, decreasing segment length can effectively reduce the calculation complexity.

Besides, since the partial correlation property, there will be large sidelobes in correlation result, these sidelobes will make acquisition probability and interference tolerance of pulsed signal reduce. According to the definitions above, it has been proved in [5] that

$$\mathrm{var}[R(\varepsilon T_c)] \approx \begin{cases} |\varepsilon|^2 / N_c, & \text{signal exists} \\ (1-2|\varepsilon|+2|\varepsilon|^2)/N_c, & \text{signal not exists} \end{cases} \quad (9)$$

where, $\mathrm{var}[\cdot]$ is the variation function, N_c is the number of code chips a integrate-dump circuit can process one time, it's equal to parameter r in FFT acquisition. Eq.(9) indicates when the alignment error ε keeps constant, the power of sidelobes increases with the reduction of N_c. For pulsed signal shown in Figure 1, PDC=0.8%, large sidelobes will seriously impact acquisition decision strategy and acquisition probability.

Suppose segment length is l_{seg}, keeping l_{seg} larger than M (the number of code chips in a pulse), by shorten l_{seg}, the power of sidelobes will reduce. So we hope l_{seg} as short as possible when it's larger than M.

Summarizing the above analysis, setting the segment length as two times of pulse length is appropriate, which means $l_{seg} = 2M$.

5.2. Pulse Truncation Problem

When the received signals are divided into segments, in some cases, the received pulse may be divided into two neighbouring segments. This is pulse truncation.

Pulse truncation causes reduction of correlation gain, and may generate two correlation peaks in two neighbouring segments, seriously impacts the acquisition performance. Thus, it's necessary to detect the pulse truncation.

Obviously, it's not practical to do this detection by estimating the value of correlation peak, because various factors (like SNR) could impact the correlation peak. Actually, we can detect the pulse truncation by the position of correlation peak.

For $l_{seg} = 2M$, if we use a segmentation algorithm different from the received signal to local code, pulse truncation could be detected. In this segmentation algorithm, each local code segment contains M chips of local code at the head of segment, the rest of segment are zero padded. When the pulse truncation happens, the correlation peak will present at the posterior half of correlation result, otherwise, the correlation peak will present at the anterior half, as illustrated in Figure 3(a), 3(b) and 3(c), respectively.

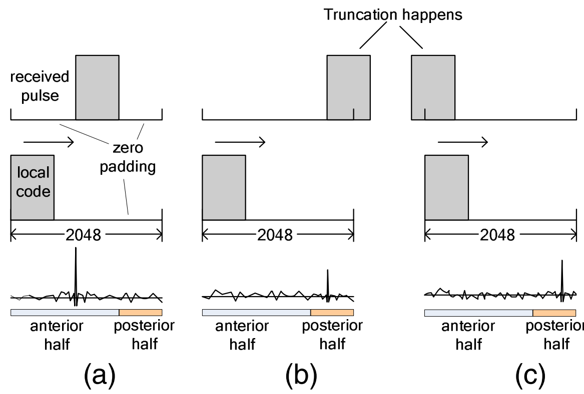


Figure 3. Pulse truncation detection method

Figure 3(a) illustrates the pulse truncation not happening case, Figure 3(b) and 3(c) illustrate the pulse truncation happening case.

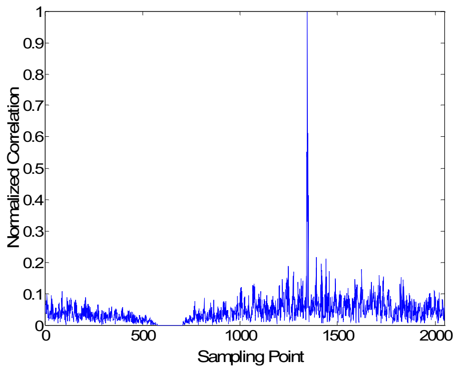
This method can not only detect the happening of pulse truncation, but also detect the position of the truncation point. Once the pulse truncation is detected, the segmentation module could adjust the segmentation to avoid it.

6. Simulation results

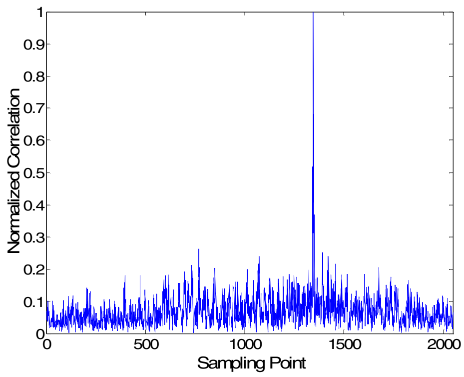
Pulsed pseudolite signal used in simulation is shown in Figure 1. We assume SNR=-5dB, sampling rate is 81.84MHz, so the number of sampling points in a pulse is 640. For both $l_{seg} = M$ and $l_{seg} = 2M$ cases, FFT points are 2048. Decision method is MTM(max to mean) method, whose decision variable is the ratio of maximum correlation value to mean correlation value, decision threshold is 6. In order to facilitate comparison, all the correlation results have been normalized.

For the comparison of correlation performances between different segment lengths, we simulate $l_{seg} = M$ and $l_{seg} = 2M$ cases. Simulation results are shown in Figure 4(a) and 4(b), respectively.

From Figure 4, it's obvious that the power of sidelobes are increasing with the increasing of segment length. The performance of $l_{seg} = M$ segmentation is better.



(a) for $l_{seg} = M$



(b) for $l_{seg} = 2M$

Figure 4. Comparison of correlation results between different segment lengths

The acquisition probability simulation results are shown in Figure 5. The curves illustrate the acquisition probabilities of $l_{seg} = M$ and $l_{seg} = 2M$ cases, respectively. It's clear that, smaller segment length corresponds to higher acquisition probability, the improvement of acquisition threshold is approximately 4dB. But from Figure 6 we also can see that, compared with continuous wave, the acquisition threshold of pulsed pseudolite signal reduces approximately 20dB. This mainly because PDC=0.8%, the maximum integration time of pulsed signal is 80chips, compared with the integration time of continuous wave, the reduction is approximately 20dB.

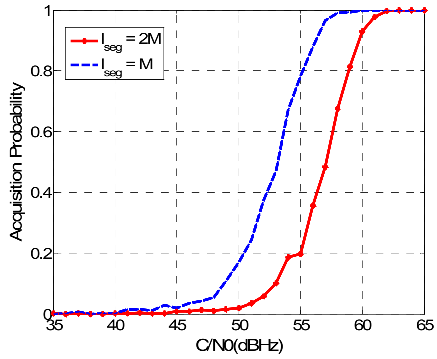


Figure 5. Comparison of acquisition probability between different segment lengths

7. Conclusions

This paper deals with problems of pulsed pseudolite signal acquisition. At the beginning of this paper, the mathematics model of pulsed pseudolite signal and its acquisition are presented. Then we propose a acquisition method using FFT. We present the structure of its major fraction, calculation process, the mean acquisition time, and detailed algorithms. Theoretical analysis and simulation results validate the correction and advantages of this method.

This method is appropriate for the pulsed signals receiving in pseudolite network environment. And because this method detects signals after correlation operation, it can be used in the case that SNR is negative, and the interference tolerance of this method is much larger than saturated receiving method.

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