Assessment of Composite PRN Code Acquisition Methods for GPS Signal

GPS組合電碼訊號擷取方法效能分析

doi:10.29979/JCSME.201002.0006

中國機械工程學刊, 31(1), 2010

Journal of the Chinese Society of Mechanical Engineers, 31(1), 2010

作者/Author： 詹劭勳(Shau-Shiun Jan);許立達(Li-Ta Hsu)

頁數/Page： 47-54

出版日期/Publication Date：2010/02

中國機械工程學刊第三十一卷第一期第47~53頁(民國九十九年)
Journal of the Chinese Society of Mechanical Engineers, Vol.31, No.1, pp.47~53 (2010)

Assessment of Composite PRN Code Acquisition Methods for GPS Signal

Shau-Shiun Jan* and Li-Ta Hsu**

Keywords：GPS, Time to First Fit (TTFF), Acquisition.

ABSTRACT

The GNSS acquisition process will need to acquire more signals transmitted by many satellite systems when more satellite systems are developed and operated. Therefore, the Time to First Fix (TTFF) of the GNSS receiver becomes a very important factor. One of the acquisition methods which are capable of reducing the computation load is the composite code acquisition method. Two composite PRN code acquisition methods are analyzed in this paper: the multi-C/A code acquisition method developed by authors and the Beach's acquisition method. This paper evaluates both composite PRN code acquisition methods in terms of the probability of detection, the probability of correct acquisition, the mean acquisition time, and the Speedup factor. A C++ program is developed to assess the performance of the GPS signal acquisition under various architectures. The real GPS intermediate frequency (IF) signals collected by a software receiver at the roof of the Department of Aeronautics and Astronautics building of National Cheng Kung University are used in this paper. As a result, the probabilities of correct acquisition, the mean acquisition time, and the Speedup factors of both acquisition methods are estimated and validated using the collected IF signal data.

INTRODUCTION

In the future, Global Navigation Satellite System (GNSS) includes not only the United States' Global Positioning System (GPS) but also European's Galileo, Russian's Global Navigation Satellite System (GLONASS) and Chinese's Beidou Satellite Navigation and Positioning system (Kaplan, 1996). The acquisition process is the dominant factor in the calculation of the time to first fix (TTFF) (Akopian, 2005; Jan, 2009). Therefore, Jan et al. proposed a new acquisition approach by generating a composite code sequence which can acquire satellites Pseudo Random Noise (PRN) codes of multiple GPS simultaneously, and the computation load was reduced greatly, in comparison to the conventional FFT approach (Jan, 2009). However, the statistical analysis of this new acquisition method is not fully studied. Moreover, this paper will further investigate the performance of this new acquisition method.

Another composite code acquisition method proposed by Beach is capable of combining GPS PRN codes to acquire multiple GPS satellites simultaneously (Beach, 1989). This acquisition method can substitute a single circuit with the multiple acquisition circuit to acquire more GPS satellites. In comparison to the conventional FFT acquisition approach, Beach's approach reduces the processing time of the acquisition process. This paper analyzes the performance difference between these two composite PRN code acquisition methods. In order to evaluate the acquisition performance difference, the probability of detection (P_d) and the probability of false alarm (P_{fa}) are important parameters, and these two parameters are a function of the detection threshold (Tsui, 2005). When using the threshold setting, there are numerous combinations of P_d and P_{fa} (Kaplan, 1996). To analyze the performance of these two composite PRN code acquisition methods, this paper calculates the P_d and the P_{fa}. Additionally, this paper defines three performance factors and they are the probability of correct acquisition, the mean acquisition time, and the Speedup factor. Using these three factors the performance difference between two composite PRN code acquisition methods can be studied.

Accordingly, this paper is organized as follows: the composite PRN code acquisition methods will be introduced in Section II. Section III presents the calculations of the probability of detection and the probability of false alarm. Section IV defines the comparison factors used in this paper. Section V

Paper Received November, 2009. Revised December, 2010. Accepted January, 2010. Author for Correspondence: Shau-Shiun Jan.

* *Assistant Professor, Department of Department of Aeronautics and Astronautics, National Cheng Kung University, Tainan 70101, Taiwan*

** *Graduate Student, Department of Department of Aeronautics and Astronautics, National Cheng Kung University, Tainan*

shows the experiment setup and experiment results, and discussion of these results is given in this section as well. Finally, Section VI presents a summary and some concluding remarks.

THE COMPOSITE PRN CODE ACQUISITION METHODS

There are two composite PRN code acquisition methods discussed in this paper: the multi-C/A code acquisition method and the Beach's acquisition method. The details of these two acquisition methods are described in the following subsections.

The Multi-C/A Code Acquisition Method

The multi-C/A code acquisition method was developed to improve the TTFF in the cold start stage of the GPS receivers (Jan, 2009) and uses one composite GPS C/A code to acquire multiple GPS satellites in an acquisition process simultaneously, and this composite code is the combination of several GPS PRN codes. The architecture of the multi-C/A code acquisition method is shown in Figure 1:

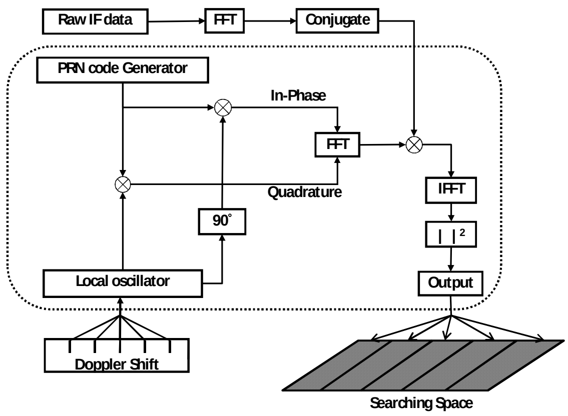


Fig. 1. The architecture of the multi-C/A code acquisition method (Jan, 2009).

In this acquisition method, the spreading code of the local signal replica is substituted by the composite code. The procedure of the composite code is to generate the PRN codes and then sum them together. The remaining procedures of the multi-C/A code acquisition method are identical to the conventional FFT acquisition method. This acquisition method is capable of combining with the other acquisition methods (Akopian, 2005, Tsui, 2005). As indicated in (Jan, 2009), if there are two GPS signals in the incoming signal, two obvious peaks would be observed in the searching space using this composite code acquisition method. This acquisition method can acquire two GPS satellites at the same time and therefore reduces the processing time of the acquisition process. However, Jan et al. mentioned the cross-correlation between the spreading codes and the incoming signal might increase the noise floor (Jan, 2009). If the noise floor is increased, the probability of detection of this acquisition method will be reduced.

The Beach's Acquisition Method

The Beach's acquisition method was developed to acquire four GPS satellites at a single correlation process (Beach, 1989). This acquisition method generates a binary composite Gold code sequence which uses a technique to change the original procedure of the Gold code sequence (Beach, 1989). There are two requirements when using this acquisition method:

1. High correlation with the multiple wanted signals.
2. Low correlation with any presented interference.

The architecture of the Beach's acquisition method is shown in Figure 2:

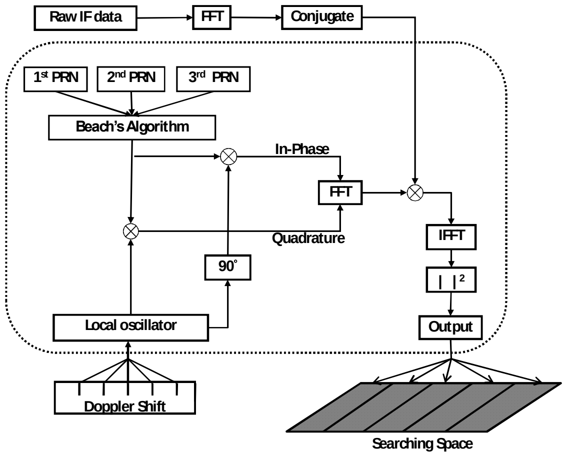


Fig. 2. The architecture of the Beach's acquisition method (Beach, 1989).

This acquisition method needs to choose three PRNs, and then derives another PRN number, and uses the special shift technique to generate the composite spreading code. Therefore, the fourth PRN number of the composite PRN code is the specific one and can't be nominated (i.e., only the first three PRNs can be arbitrarily nominated). After generating the composite PRN code, the remaining procedures are identical to the conventional FFT acquisition method. Similar to the multi-C/A code acquisition method, this acquisition method reduces the computation load while acquiring multiple GPS satellites simultaneously. However, the drawback of this composite PRN code acquisition method is that it must choose three PRNs to compose the composite code. Therefore, in some cases, the Beach's acquisition method might not be able to acquire the

GPS satellite successfully.

THE STEADY-STATE RESPONSE TO STEERING INPUT

This section presents the calculations of the probability of detection and the probability of false alarm for the acquisition methods in this paper. This paper uses a simulated signal to evaluate these probabilities for the two composite PRN code acquisition methods. If a linear acquisition method generates a complex output, the noise in the in-phase and the quadrature channel will become a Gaussian distribution. As a result, the amplitude of the noise will become a Rayleigh distribution (Lin, 2000) as shown in (1):

$$p_n(z) = \frac{z}{\sigma_n^2}\exp\left(-\frac{z^2}{2\sigma_n^2}\right) \qquad (1)$$

where the σ_n^2 is the variance of the output noise. Therefore, the probability of false alarm (P_{fa}) can be determined by (2):

$$P_{fa} = \int_{V_t}^{\infty} p_n(z)\,dz = \exp\left(-\frac{V_t^2}{2\sigma_n^2}\right) \qquad (2)$$

where V_t is the detection threshold. Rearranging (2), yields the V_t in terms of P_{fa} and σ_n as shown in (3).

$$V_t = \sigma_n\sqrt{-2\ln P_{fa}} \qquad (3)$$

The Equations (1-3) are based on the assumption mentioned above. To calculate P_{fa} of the two composite code acquisition methods, we have to verify whether the noise distribution is Rayleigh distribution or not. Because these two acquisition processes produce a cross-correlation interferences (i.e., the nonlinear process). The Gaussian white noise is used in the simulated signal to verify the resulting noise distribution. If the noise distribution fits the Rayleigh distribution, then P_{fa} can be obtained by the above equations. When the noise variance is obtained, the Rayleigh distribution can be presented in the histogram of the output noise amplitude. Figure 3 indicates the noise amplitude histogram and the Rayleigh distribution curve of the simulated noise derived by the multi-C/A code acquisition method. The top subplot points out the result using the conventional FFT acquisition method to process one PRN, and the bottom three subplots show the result using the composite code to process two, three and four PRNs, respectively.

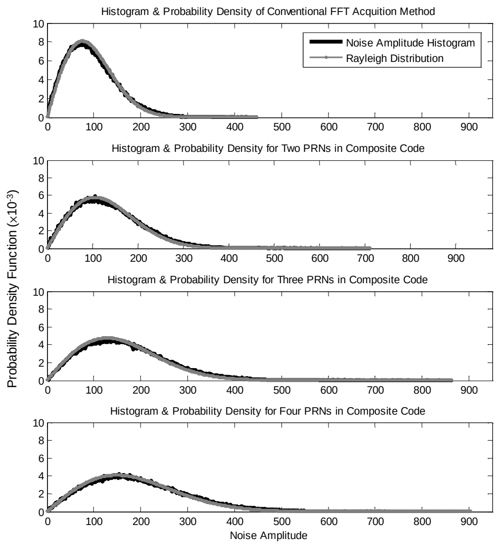


Fig. 3. The noise amplitude histogram and the Rayleigh distribution curve of the simulated noise derived by the multi-C/A code acquisition method with one, two, three, and four PRNs in the composite code.

In Figure 3, one can note that the noise amplitude histogram generated by the multi-C/A code acquisition method is similar to the ideal Rayleigh distribution. Similarly, Figure 4 is for the Beach's acquisition method. The upper subplot of the Figure 4 indicates the result generated by the conventional FFT acquisition method, and the bottom subplot is the result of the Beach's acquisition method.

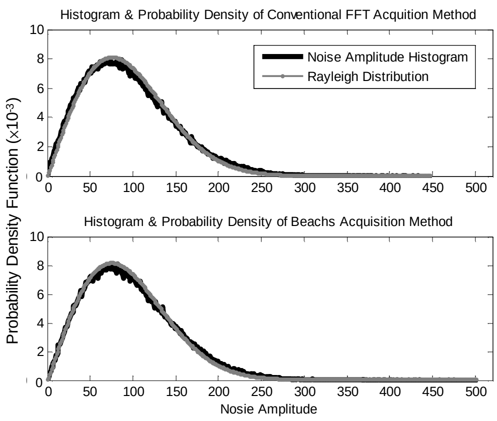


Fig. 4. The noise amplitude histogram and the Rayleigh distribution curve created by the conventional FFT acquisition method (top) and the Beach's acquisition method with three PRNs in the composite code (bottom).

In Fig. 4, the noise amplitude histogram generated by the Beach's acquisition is similar to the ideal Rayleigh distribution. Therefore, both composite code acquisition methods are able to apply the Eq. (1-3) to calculate V_t. The simulated signal in this paper consists of the GPS L1 signals with the Gaussian noise. In this case, the simulated signal is the superposition of a complex Gaussian component with a signal, and the envelope of this case is a Ricean distribution (Lin, 2000) which can be written as:

$$p_s(z) = \frac{z}{\sigma_n^2} e^{-\frac{z^2+A^2}{2\sigma_n^2}} I_0\left(\frac{zA}{\sigma_n^2}\right) \quad (4)$$

where A is the amplitude of the input signal, and I_0 is modified Bessel function of zero order. Therefore, the probability of detection (P_d) can be determined by (5):

$$P_d = \int_{V_t}^{\infty} p_s(z)\,dz \quad (5)$$

This paper uses numerical method to calculate the integration of the probability of detection. The P_d and P_{fa} are functions of the detection threshold. By Eq. (3), when the single trail of P_{fa} is set, the threshold can be estimated. After P_{fa} is estimated, P_d can be calculated. In this paper, no more than one false detection is allowed for every one hundred searches. For example, if the total outputs are 34,372,800 for one hundred searches, then the probability of false alarm is 1/34,372,800, and the threshold can be determined to estimate the P_{fa}.

THE PERFORMANCE COMPARISON FACTORS

This paper defines three performance factors: 1) the probability of correct acquisition, 2) the mean acquisition time, and 3) the *Speedup* factor. Each factor plays a different role in evaluating the performance of the acquisition method. The probability of correct acquisition represents the acquisition capability. To calculate the probability of correct acquisition, the conventional FFT acquisition method is used to find the satellites that always exist of the signal in each trail. Then the multi-C/A code acquisition method and the Beach's acquisition method use the composite codes which consist of the PRN codes of the satellites which are found by the conventional FFT acquisition method to acquire the same signal again to calculate the probability of finding these satellites in the same searching space. If all the satellites are acquired simultaneously, we define this acquisition to be a successful acquisition. For example, the signal length is 500ms, and PRN1, PRN2, and PRN3 always exist in each acquisition trail of the signal, and then we use the composite code acquisition method with PRN1, PRN2, and PRN3 to acquire the same signal again. A successful acquisition is that PRN1, PRN2, and PRN3 are simultaneously acquired in one acquisition process. If there are 450 successful acquisitions in 500 acquisition processes, the probability of correct acquisition is 90%. The mean acquisition time is the average time of total acquisition processes using the C++ program developed in this paper. Therefore, if the mean acquisition time of the specific acquisition method is smaller than the conventional FFT acquisition, then the specific acquisition method reduces the computation load. The *Speedup* factor is the ratio of the mean acquisition time of the conventional FFT acquisition method and that of the specific acquisition method. Therefore, the higher *Speedup* factor indicates the more saving in the processing time. Equation (6) defines the *Speedup* factor.

$$Speedup = \frac{\text{mean acquisition time of conventional method}}{\text{mean of acquisition of the specific method}} \quad (6)$$

SIMULATION AND EXPERIMENT RESULTS

In order to evaluate the probability of detection and the probability of false alarm, the signal model used in the simulation test is introduced. The signal model is shown as the following:

$$S = A \times C \times \exp\left(j2\pi \left(f_{IF} + f_{dopper} \right) + \theta \right) \quad (7)$$

where A is the signal amplitude, C is the spreading code, f_{IF} is the frequency of intermediate frequency (IF), f_d is the Doppler shift, and θ is the carrier phase. We can adjust the signal amplitude to obtain the desired signal-to-noise ratio (SNR) value, and the amplitude can be written as:

$$A = \sqrt{2} n_{st} \left(10^{dB/20} \right) \quad (8)$$

where n_{st} is the standard deviation of the noise, dB is the desired SNR value (Tsui, 2005). This paper conducts three tests to analyze the P_d and the P_{fa} of the composite code acquisition methods, and there are 121000 processes in each test. In the first test, the simulated signal consists of one GPS satellite signal and the white Gaussian noise. Figure 5(a) shows the resulting P_d of the conventional FFT acquisition method, the multi-C/A code acquisition method, and Beach's acquisition method of the first test. As shown in Fig. 5(a), the two composite code acquisition methods need higher SNR than the conventional FFT acquisition method to acquire the GPS signal for the same P_d. Because the composite code acquisition methods generate the cross-correlation noise, it is reasonable that the performance of P_d of the conventional method is better than those two composite code acquisition methods. In order to investigate the attenuation of the signal strength caused by the composite code acquisition methods, Fig. 5(a) is normalized and zoomed in and it is shown in the right subplot of Fig. 5(a). The range of the zoomed in area is between 98.5% and 100% of the P_d. The SNR of the signal is normalized to be 0dB when the P_d of the conventional FFT acquisition method is 99%.

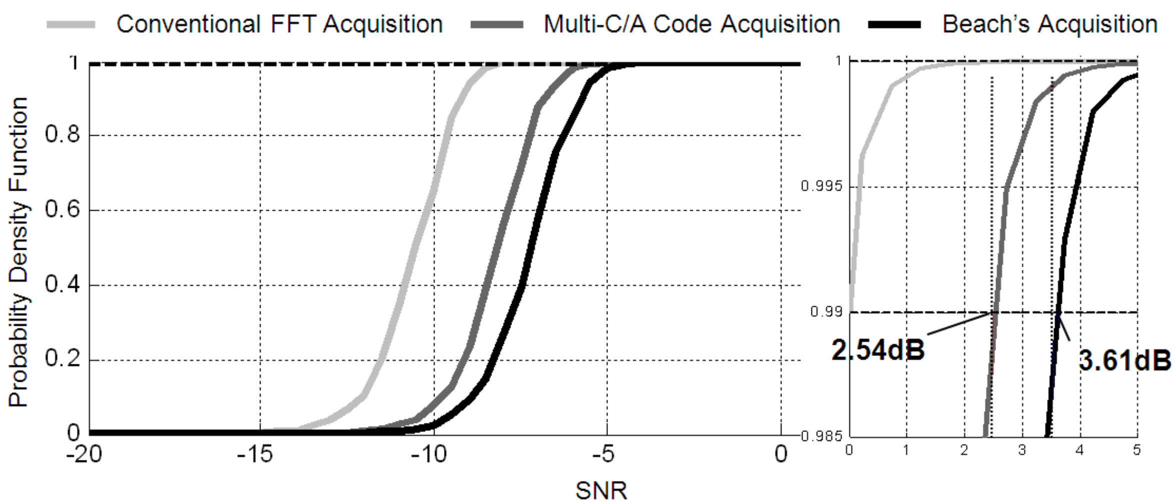
When the P_d is 99% for both the multi-C/A code acquisition method and the Beach's acquisition method, the SNRs of the signal are 2.54dB and 3.61dB, respectively. It means that for the same simulated signal the sensitivity of the multi-C/A code acquisition method and that of the Beach's acquisition method are less than that of the conventional FFT method. The difference of SNR between the multi-C/A code acquisition method and the Beach's acquisition method indicates that the sensitivity of the multi-C/A code acquisition method is better than that of the Beach's acquisition approach at the same P_d requirement. In the second test, the simulated signal contains two GPS satellite signals and the white Gaussian noise, and the result of the second test is shown in Figure 5(b). As shown in Fig. 5(b), the sensitivity of the multi-C/A code acquisition method is better than that of Beach's approach method for this test. For instance, when the P_d is 99%, there are 2.34dB and 2.93dB signal SNR differences for using the multi-C/A code acquisition method and the Beach's acquisition method in comparison to the conventional FFT method, respectively. In the third test, the simulated signal contains three GPS satellite signals and the white Gaussian noise, and the result of the third test is shown in Figure 5(c). As shown in Fig. 5(c), the sensitivity of the multi-C/A code acquisition method is still better than that of the Beach's approach. When the P_d is 99%, the signal SNR difference is 4.48dB for the multi-C/A code acquisition method and it is 4.58dB for the Beach's acquisition method in comparison to the conventional FFT method. The SNR difference between the multi-C/A code acquisition method and the Beach's acquisition method is only 0.1dB. Therefore, if there are three GPS satellites' signals existed in the simulated incoming signal, the sensitivities of these two composite code acquisition methods are very similar when P_d is 99%.

The real data used in this paper is collected by a software defined GPS receiver (Tsui, 2005) at the roof of the Department of Aeronautics and Astronautics building of National Cheng Kung University. The sampling frequency and IF are 16.368MHz and 4.1304MHz, respectively. There are three signals in the experiment, and their data length is 500 ms. The date and time of the three signals are shown below:

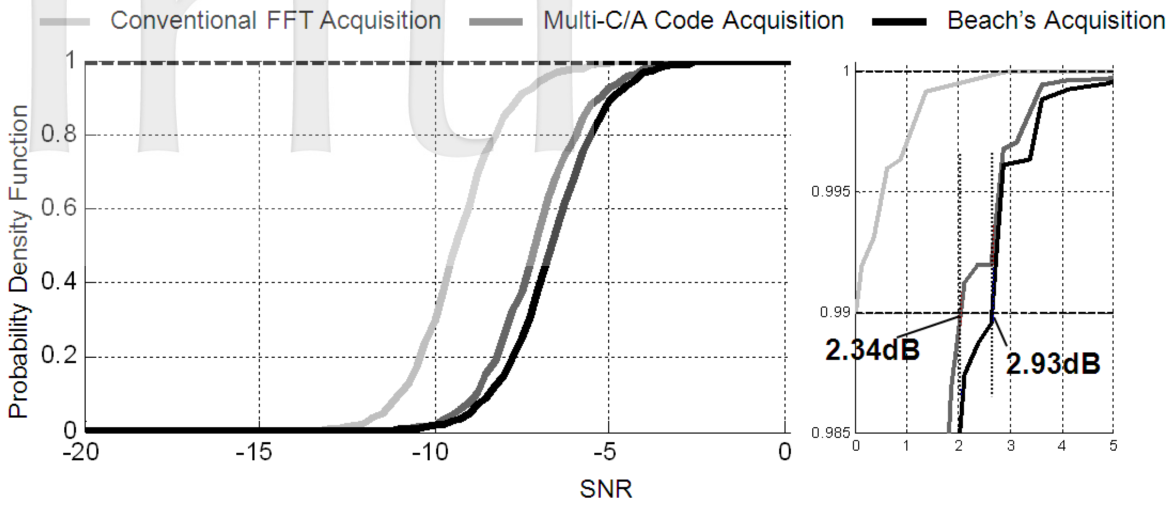
Table 1: The date and time of the three signals used in the experiment.

	Signal 1	Signal 2	Signal 3
Date	17 Dec., 2007	18 Dec., 2007	19 Dec., 2007
Time (UTC)	07:25:33	10:58:12	09:08:24

(a) first test



(b) second test



(c) third test

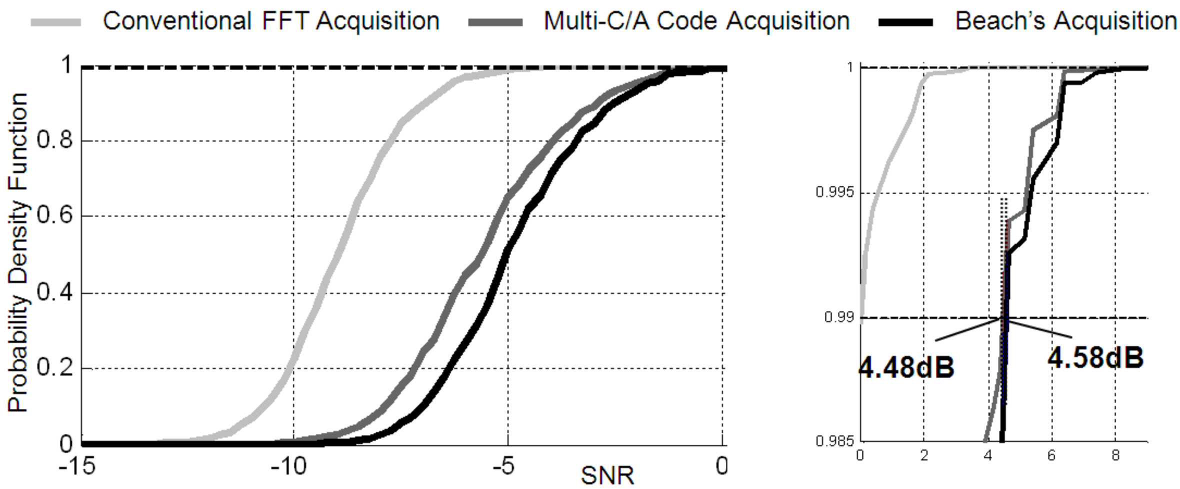


Fig. 5. The P_d of the conventional FFT acquisition method, the multi-C/A code acquisition method, and the Beach's acquisition method for three tests.

To investigate the probability of correct acquisition, we have to use the conventional FFT acquisition method to acquire the satellites which always exists in every trail (i.e., the satellites can be acquired in every millisecond). We then use the two composite code acquisition methods to re-acquire the same signal and check whether the acquisition methods can acquire the satellites simultaneously or not. The resulting probability of correct acquisition of the experiment is shown in Figure 6.

In Figure 6, the experimental result of the multi-C/A code acquisition method for Signal 1 is 71.6%, and it means there are 358 processes of 500 acquisition processes which the multi-C/A code acquisition method is able to acquire three satellites simultaneously. The performance of the multi-C/A code acquisition method is better than that of the Beach's acquisition approach for all Signals 1, 2 and 3, and the probability of correct acquisition of the multi-C/A code acquisition method is at least 25% higher than that of the Beach's acquisition method. That is, to acquire three satellites simultaneously in one acquisition process, the multi-C/A code acquisition method works better.

The processing time of the composite code acquisition methods needs to be investigated as well. In this paper, the processing time is defined as the total time taken by the complete acquisition processes program, and it is measured by calling the system clock. All the programs are developed in Microsoft Visual Studio 2005 C++ on the Windows XP platform. A desktop computer with Intel® Pentium D processor (3.0GHz) and 2GB RAM is used in this paper. The C++ program is also implemented to evaluate the processing time of the acquisition processes for the parameter of the Doppler shift bins, and this parameter is to investigate the size of searching space. The range of Doppler shift is from -5000 Hz to 5000 Hz. Then the number of Doppler shift bins used to evaluate the processing time are 11, 21, and 41, and the corresponding Doppler shift steps are 1000 Hz, 500 Hz, and 250 Hz, respectively. Figure 7 is the experimental result of the mean acquisition time. In Fig. 7, the conventional FFT acquisition method takes more processing time than the other two composite code acquisition methods do. Consequently, these two composite code acquisition methods are capable of reducing the computation load.

To investigate the performance of these two composite code acquisition methods, the Speedup factors of both methods are calculated, as shown in Figure 8. In Fig. 8, the Speedup factor of the Beach's acquisition method is higher than that of the multi-C/A code acquisition method. This means that the Beach's acquisition method needs less computational effort than the multi-C/A code acquisition method to generate the composite code.

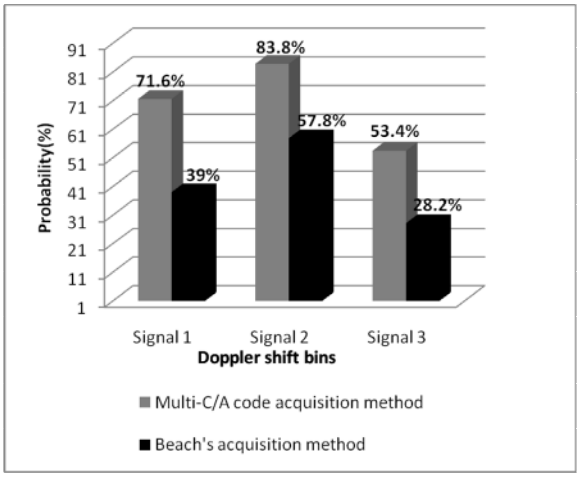


Fig. 6. The probabilities of correct acquisition of the multi-C/A code acquisition method and the Beach's acquisition method.

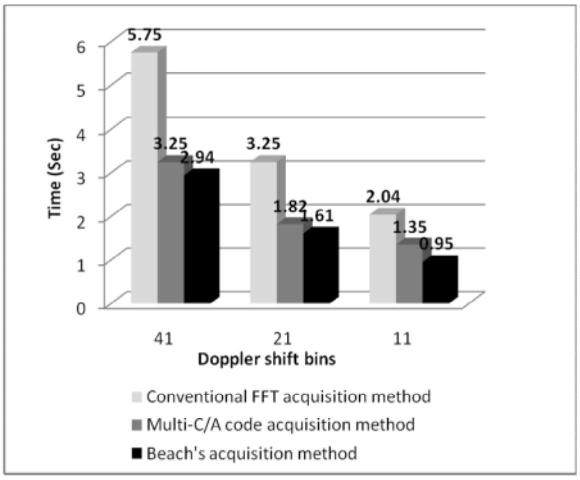


Fig. 7. The mean acquisition time of the conventional FFT acquisition method, the multi-C/A code acquisition method and the Beach's acquisition method.

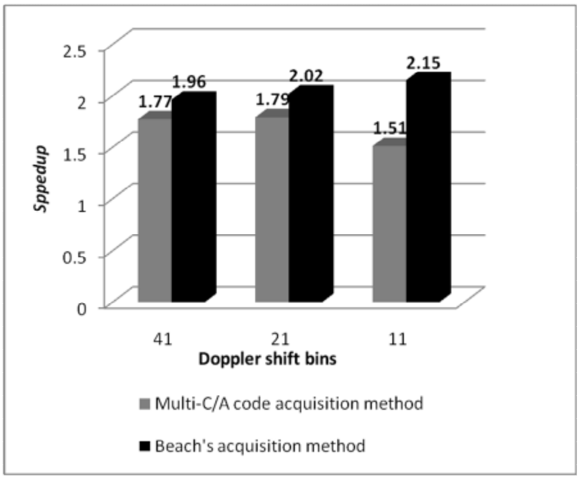


Fig. 8. The *Speedup* factors of the multi-C/A code acquisition method and the Beach's acquisition method.

Based on these simulation and experiment results, the multi-C/A code acquisition method performs better in the probability of detection and the probability of correct acquisition tests, while the Beach's acquisition method has better the mean acquisition time and the Speedup factor.

CONCLUSIONS

Because there will be more GNSSs available in the future, the computation load of the acquisition process will increase as well. The composite code acquisition method is a solution for solving this problem. This paper evaluated the probability of detection and the probability of false alarm for the multi-C/A code acquisition method and the Beach's acquisition method with three different simulated signals. The probability of correct acquisition, the mean acquisition time, and the Speedup factor are also investigated for these two composite code acquisition methods using three collected GPS signals in this paper. Based on the experimental results, the multi-C/A code acquisition method has better performance in the probability of detection and the probability of correct acquisition, and the Beach's acquisition method reduces more computational load in comparison to the conventional FFT acquisition method. The next step of this work is to investigate the multiple GNSSs composite code acquisition methods.

ACKNOWLEDGMENTS

The work of this paper is supported by the Taiwan National Space Organization under research project NSC 98-2221-E-006-122. The authors gratefully acknowledge this support.

REFERENCES

Akopian, D., "Fast FFT Based GPS Satellite Acquisition Method," *IEE Proceeding of Radar Sonar Navigation*, Volume 152, Number 4, (2005).

Beach, M.A., "A Novel Acquisition Technique for NAVSTAR GPS," *Fifth International Conference on Radio Receivers and Associated Systems*, July 23-27, (1989).

Jan, S.S., Lin, Y.C., "A New Multi-C/A Code Acquisition Method for GPS," *GPS Solutions*, Volume 13, Number 4, September, (2009).

Jan, S.S., Sun, C.C., "The Weighted Coherent Overlapping Tracking Method for GPS Receivers," *Journal of the Chinese Society of Mechanical Engineers*, Volume 30, Number 3, June, (2009).

Kaplan, E.D., *Understanding GPS: Principles and Application*, Artech House Publishers, Boston, MA, (1996).

Lin, M., Tsui, J.B.Y., "Comparison of Acquisition Methods for Software GPS Receiver," *Proceedings of ION GPS 2000*, Salt Lake City, UT, September 19-22, (2000).

Tsui, J.B.Y., *Fundamentals of Global Positioning System Receivers—A Software Approach.* second edition, John Wiley & Sons, Inc. (2005).

GPS 組合電碼訊號擷取方法效能分析

詹劭勳　　許立達

國立成功大學航空太空工程學系

摘 要

GNSS 訊號擷取程序將處理更多的衛星訊號，因為未來將有更多的衛星導航系統建置。因此，首次定位時間將成為未來 GNSS 接收機的重要效能因子，目前有許多學者提出使用組合電碼的方式來降低訊號擷取程序的運算量，本文針對其中兩種組合電碼擷取方法進行效能評估與分析：第一種是作者提出的多重電碼擷取方法，第二種為 Beach 所提出的擷取方法。效能分析的項目包括：發現機率，正確擷取機率，平均擷取時間和加速因子。本文撰寫 C++程式以進行各種架構下訊號擷取效能分析，本文 GPS 訊號來源為利用軟體接收機放置於成大航太系頂樓收集之真實中頻訊號，因此，本文中之各項效能分析皆是以真實採集的 GPS 中頻訊號來進行估測與驗證。