International Global Navigation Satellite Systems Society
IGNSS Symposium 2007

The University of New South Wales, Sydney, Australia
4 – 6 December, 2007

A Fast GPS Signal Acquisition Method for High Speed Vehicles Using INS velocity and Multiple Correlators

Ho Cheol Jeong
Department of Electronics Engineering, Chungnam National University, South Korea
+82-42-821-7706; +82-42-823-5436; hochol@cslab.cnu.ac.kr

Jeong Won Kim
Department of Electronics Engineering, Chungnam National University, South Korea
+82-42-821-7709; +82-42-823-5436; kimjw@cnu.ac.kr

Dong-Hwan Hwang
School of Electrical and Computer Engineering, Chungnam National University, South Korea
+82-42-821-5670; +82-42-823-5436; dhhwang@cnu.ac.kr

Sang Jeong Lee
School of Electrical and Computer Engineering, Chungnam National University, South Korea
+82-42-821-6582; +82-42-823-5436; eesjl@cnu.ac.kr

ABSTRACT

GPS/INS integrated navigation systems have been used for guided munitions. By adding the navigation system into unguided munitions, accuracy can be highly improved. In these applications, GPS receivers have to meet certain requirements such as gun-hardening, fast signal acquisition and jammer tolerance. Especially, the signal should be acquired as fast as possible since mission time is very short.

Several methods have been proposed for fast acquisition. These methods make it possible to reduce acquisition time by searching code phases in parallel. However, in military applications, the Doppler frequency range to be searched should be reduced since the Doppler frequency range is wider than conventional vehicle.

This paper proposes a fast acquisition method using INS velocity and multiple correlators for high speed vehicles. In order to reduce acquisition time, range of the Doppler frequency is reduced using INS velocity and number of code phase to be searched is reduced using multiple correlators. Monte-Carlo simulation was carried out to show performance of the proposed method.

KEYWORDS: Fast acquisition, INS velocity, Multiple correlators.

1. INTRODUCTION

In order to provide a position of a vehicle, acquisition, tracking, data synchronization and demodulation are carried out in a GPS receiver[3]. The acquisition detects presence of the GPS signal and is a two-dimensional search process. It searches over expected Doppler frequency and code phase. The number of search cells depends on range of the Doppler frequency and the number of code phase search and should be reduced in order to accomplish a fast acquisition.

To get a fast acquisition, FFT(Fast Fourier Transform), matched filter and multiple correlators have been used[5, 7]. By using FFT, the code phase can be searched in parallel. However, this method requires heavy computation. The method using matched filter and multiple correlators can also be implemented for the parallel search process in the code phase.

In resent year, GPS receivers are widely used in military applications. The military GPS receivers have to meet certain requirements: fast acquisition, high jammer tolerance, tracking accuracy and battlefield security. Some applications of smart munitions require that their missions be completed within 20 ~ 30 second. When the GPS receiver is used for these applications, the acquisition should be completed in fast. In addition to this, since lots of military vehicles are operated in high speed, the Doppler frequency is larger than that of conventional vehicle.

This paper proposes a fast acquisition method for high speed vehicles using INS velocity and multiple correlators. When velocity from INS is available, the Doppler frequency can be estimated within a certain limit. By using the INS velocity information and multiple correlators simultaneously in the acquisition, the search space can be greatly reduced since search range in Doppler frequency and search number in code phase can be simultaneously reduced.

2. SEARCH AREA FOR ACQUISITION

Search area of the code phase and Doppler frequency for acquisition is shown in figure 1. The area is divided into cells. The number of cells is directly proportional to the range of code phase and Doppler frequency and is expressed in equation (1).

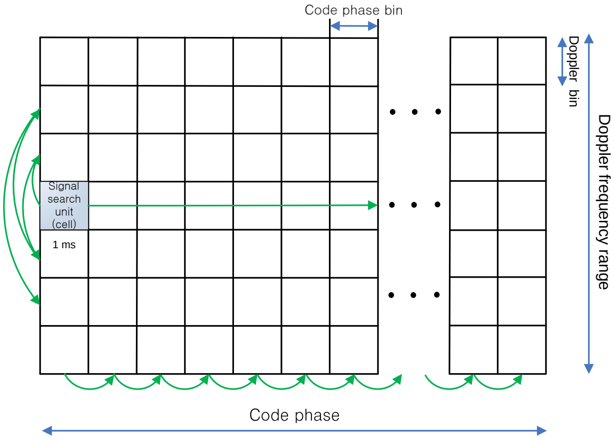

Figure 1. Search area for acquisition

$$N_{search} = N_{dopp} \times N_{code} = \frac{f_{dopp}}{f_{bin}} \times \frac{\tau_{code}}{\tau_{bin}} \quad (1)$$

where N_{search}, N_{dopp} and N_{code} are number of total search cells, number of Doppler frequency search unit and number of code phase search unit, respectively. f_{dopp} is Doppler frequency and f_{bin} is Doppler frequency bin. τ_{code} is code phase range and τ_{bin} is code phase bin. In case of GPS L1 C/A signal, the code phase bin and Doppler frequency bin are usually selected 0.5chip and 500Hz, respectively. f_{dopp} includes receiver reference clock error of which value in 4.5kHz when 3ppm TCXO is used in GPS receiver. When the vehicle speed in 300m/s, Doppler frequency becomes 11kHz since the frequency shift caused by relative motion between satellite and vehicle is 6.5kHz. When the vehicle speed is 1000m/s, the Doppler frequency increases to 14.5kHz as shown in figure 2. In this case, the number of search cells is 118,668.

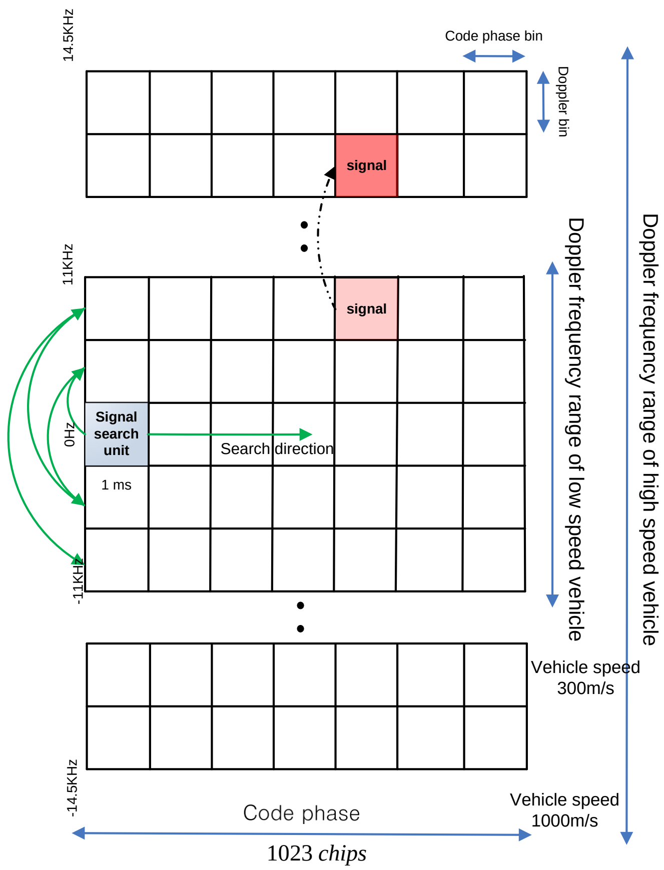

Figure 2. Signal search area in high speed vehicles

3. SIGNAL ACQUISITON USING INS VELOCITY AND MULTIPLE CORRELATORS

Since the Doppler frequency range for acquisition depends on the relative motion of satellite and vehicle as shown in figure 3. The Doppler frequency can be expressed in equation (2)

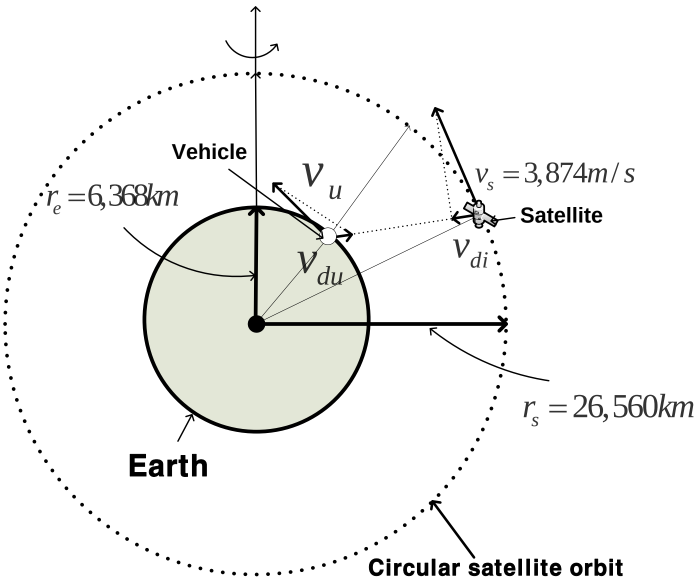

Figure 3. Relative motion between GPS satellite and vehicles

$$f_{dopp} = (\frac{v_s - v_u}{C} \cdot \mathbf{l_i})L_1 + f_{clock} \tag{2}$$

where v_s and v_u are velocity of satellite and vehicle, respectively. $\mathbf{l_i}$ is the line of sight vector between satellite and vehicle. L_1 and C denote GPS carrier frequency(1575.42MHz) and speed of light($3\times10^8 m/s$), respectively. f_{clock} denotes receiver reference clock error. Since speed of the satellite is 3,874m/s, Doppler frequency can be estimated when the velocity information from INS is available. The Doppler frequency can be estimated using velocity of INS. If the velocity has no error, the Doppler frequency can be searched at once. However the estimated Doppler frequency has error and can be expressed in equation (3)

$$f_{dopp} = (\frac{v_s - v_{INS}^e}{C} \cdot \mathbf{l_i})L_1 + f_{clock} \tag{3}$$

where λ_{L1} is GPS L1 carrier wavelength and v_{INS}^e is INS velocity error in the ECEF(Earth Centered Earth Fixed) coordinate system. In this case Doppler frequency can be expressed in equation (3). Note that 500Hz Doppler corresponds to 95m/s. When tactical grade IMU is used in the navigation system, velocity error does not exceed this value in 20 ~ 30 seconds. Therefore, it can be seen that the number of search cells can be greatly reduced

The code phase can be searched in parallel using multiple correlators. When multiple correlators are used, number of search cells in one time is equal to the number of correlator of the multiple correlators as shown in figure 4. As a result of this, it can be regarded that the size of the search cell.

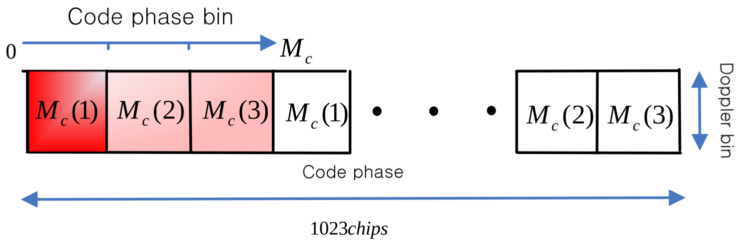

Figure 4. Code phase search using multiple correlators

When the INS velocity and multiple correlators are used simultaneously, the number of cells can be expressed in equation (4)

$$N_{search} = \frac{f_{dopp}}{f_{bin}} \times \frac{\tau_{code}}{\tau_{bin} M_c} \tag{4}$$

When the proposed method is applied, GPS receiver structure for acquisition is shown in figure 5

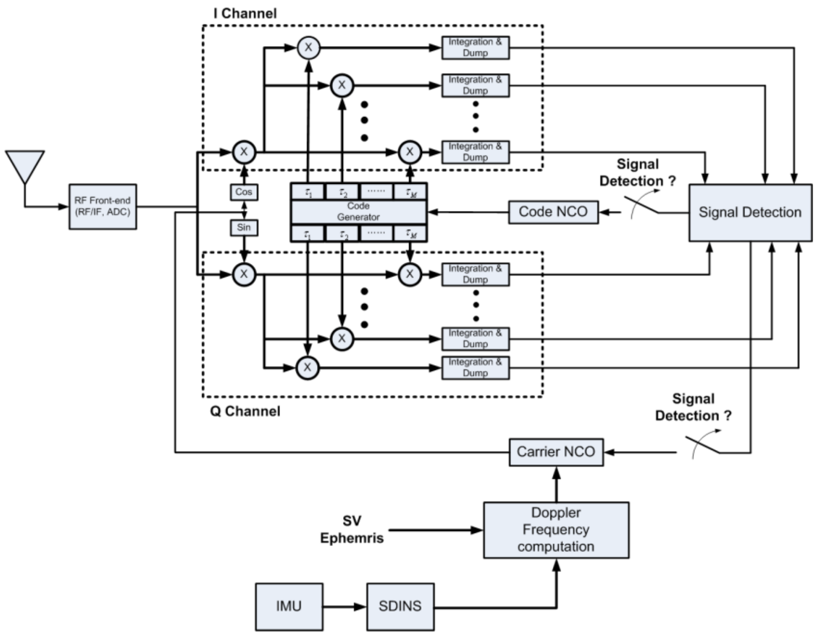

Figure 5. Acquisition structure of a GPS receiver

Average acquisition time can be calculated using equation (5)[7].

$$\bar{T}_{MA} = \left(\frac{2-\bar{P}_D}{2\bar{P}_D}\right)\left[k_p(1-(1-\bar{P}_{FA}))^{M_c}+1\right]\frac{f_{dopp}}{f_{bin}}\frac{\tau_{code}}{\tau_{bin} M_c} T_{dwell} \tag{5}$$

where $\bar{T}_{MA}$ is the average time of search, $\bar{P}_D$ is the detection probability, $\bar{P}_{FA}$ is the false alarm probability, k_p is the false alarm coefficient and T_{dwell} is the dwell time.

4. PERFORMANCE EVLUATION

Experiment setup for performance evaluation is shown in figure 7. It consists of a host computer, a GPS simulator, a GPS signal acquisition board and an IMU simulator. The GPS signal simulator, GSS7700 manufactured by Spirent®, provides multiple functions for generation GPS RF signal. The IMU simulator, SimINERTIAL, manufactured by Spirent®, provides a substitute for the inertial measurement. The bias of accelerometer and gyro are 8.5mg and 3600deg/hr, respectively. Simulation was carried out 50 times. The speed trajectory of the vehicle is given in figure 8. The vehicle is stationary for 2 minute. And then, the speed rises to 1000m/s.

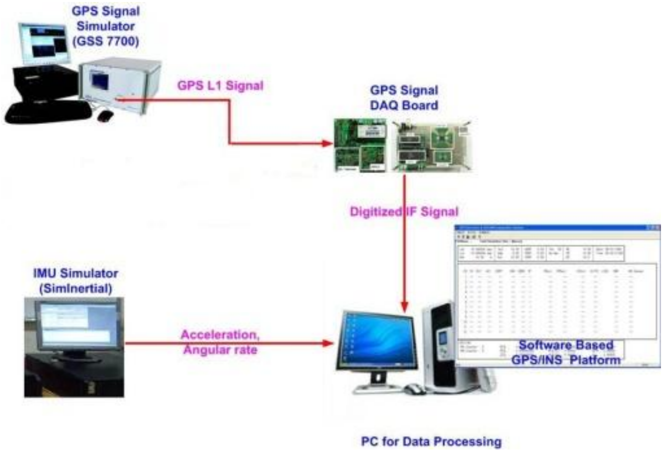

Figure 7. Experiment setup

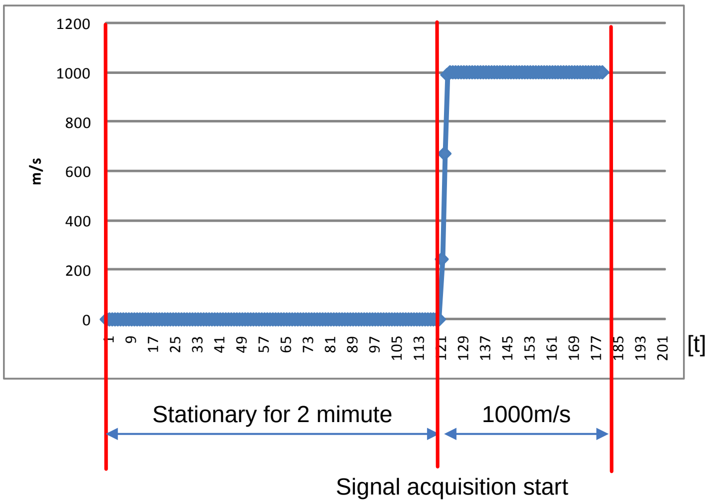

Figure 8. Speed of the vehicle

Figure 9 shows average acquisition time versus the number of correlators. When one correlator is used, average acquisition time is 16.7 second. It can be seen from figure 9 that average acquisition time decreases as number of correlators increases. Twenty correlators reduce average acquisition time to 2 second.

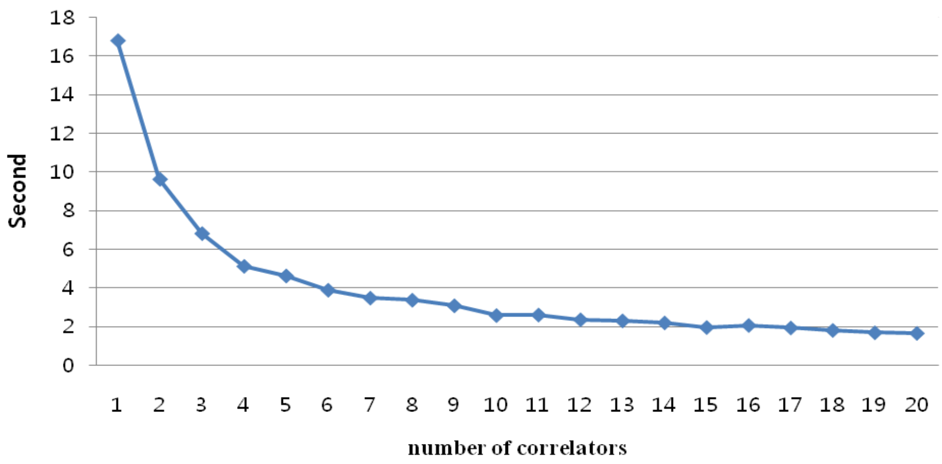

Figure 9. Average acquisition time versus number of correlators

Figure 10 shows error of the estimated Doppler frequency which is obtained from IMU output in pure navigation process. It can be observed that the Doppler frequency error within 30 seconds is less than 500Hz. In this case, number of search units is 1.

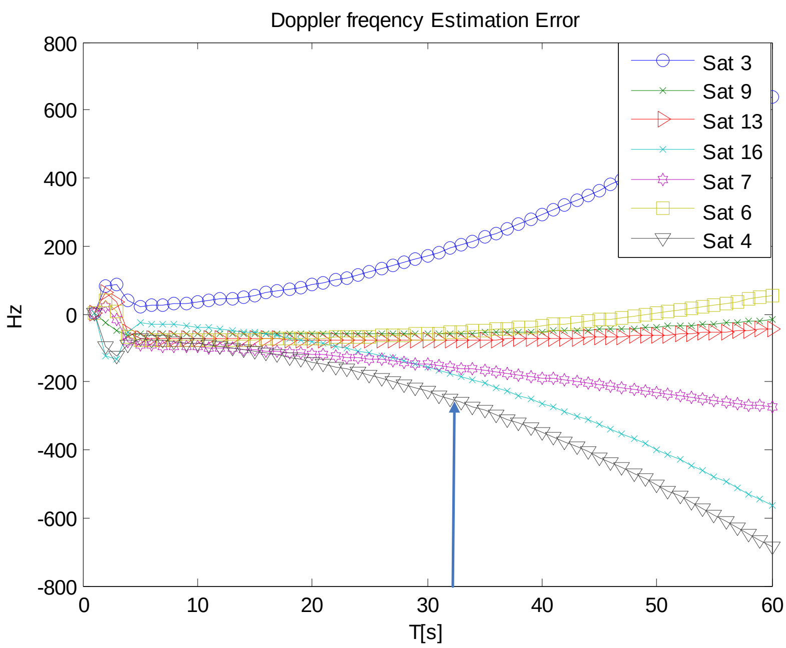

Figure 10. Doppler frequency estimation error

Figure 11 shows the average acquisition time when the proposed method is applied. It can be observed from figure 11 that average acquisition time is less than 0.4 second when INS velocity and 20 correlators. Acquisition time is given in table 1 when the number correlators are changed without INS velocity and with INS velocity. It can also be seen that almost 15 sec signal acquisition time can be reduced as INS velocity is used.

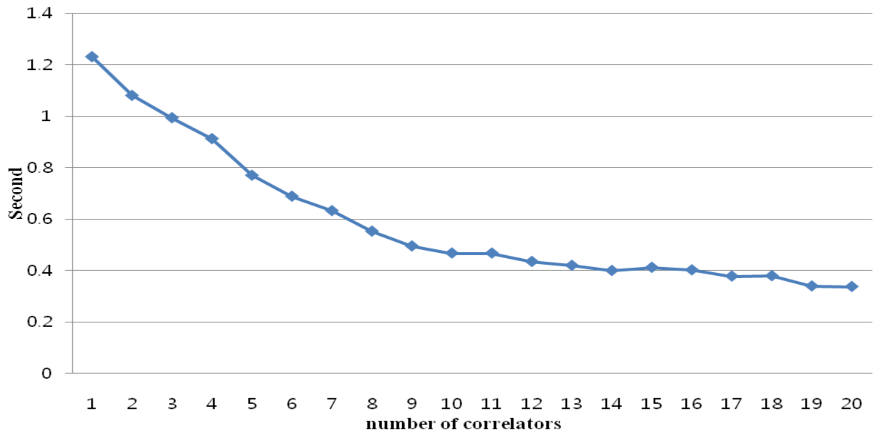

Figure 11. Average acquisition time of the proposed method

	Correlator	INS and Correlator
The number of correlators	Average time	Average time
1	16.78301	1.023167
2	9.620449	1.08101
3	6.815145	0.99404
4	5.124144	0.91254
5	4.626218	0.77
6	3.891186	0.68852
7	3.481253	0.63227
8	3.374303	0.55237
9	3.086094	0.4948
10	2.580723	0.46737
11	2.60971	0.46712
12	2.366464	0.43425
13	2.30527	0.4194
14	2.2071	0.39932
15	1.966628	0.41158
16	2.070131	0.40178
17	1.939585	0.37755
18	1.814572	0.37885
19	1.690411	0.33902
20	1.660559	0.33684

Table 1. Comparison of the average acquisition time

5. CONCLUDING REMARKS AND FURTHER STUDY

In this paper, a fast GPS signal acquisition method using INS velocity and multiple correlators has been proposed. Since Doppler frequency is larger than conventional vehicles when the vehicle speed is high, The proposed method reduces Doppler frequency and the number of code phase to search by using the INS velocity information and multiple correlators simultaneously. Even though estimated Doppler frequency has uncertainty due to the INS velocity error, the signal can be detected within 1~3 cells. The experimental result shows average acquisition time is less than 0.4 second when INS velocity and 20correlators.

REFERENCE

[1] Dowdle, J. R. and Flueckiger, K. W.(1996) A GPS/INS guidance system for navy 5 prokectiles, *Proceedings of ION 52nd Annual Meeting*, pp.19-21.

[2] Holmes, J. K. and Chen , C. C.(1977) Acquisition and performance of PN spread-spectrum system, *IEEE Transactions on Communications*, Vol. Com-25, No. 8, pp. 778-783.

[3] Kaplan , E. D. and Hegarty, C. J.(1996) *Understanding GPS : Principles and Applications* (second edition) , Artech House.

[4] Lowzow, J. B. (1997) Analysis of direct P(Y)-acquisition," *NAVIGATION: Journal of The Institute of Navigation*, Vol. 44, No. 1, pp.89-98.

[5] Seo, H. S.(2003) A fast searching method for the GPS signal acquisition, *Ph.D Thesis*, Department of Electronics Engineering, Chungnam National University, Korea.

[6] Tsui, J. B.(2004) *Fundamentals of Global Positioning System Receivers A Software Approach* (second edition) , Wiley-Intersciene.

[7] Van Nee, D. J. R. and Coenen, A. J. R. M.(1991) New fast GPS code-acquisition technique using FFT, *IEE Electronics Letters*, Vol. 27, No. 2 pp.158-160.

[8] Zein, N. F., Chambers W. G. and Clarkson, T. G.(1990) Use of matched filters for serial acquisition in a fast frequency-hopping system, *Proceedings of IEEE Military Communications Conference*, MILCOM, Vol.1, pp. 161-165.