Speedup Technique of FFT based Signal Acquisition at Software-based GNSS Receiver

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Abstract

Software-based GNSS receivers have the great advantage in flexibility compared with conventional receivers. But it has some problems to processing IF level Signal RAW data, need long time to process long term data and TTFF is long because the process is too slow. So this time, we concentrated on the signal acquisition, and examined the speedup technique. Using this technique, the acquisition was speedup dramatically, and signal-to-noise ratio was improved.

Keywords: Software based GPS receiver, fast acquisition, week signal acquisition, robustness improvement

1. Introduction

The modernization of the Global Positioning System(GPS), the revival of Russian GLONAS and the advant of European Galileo system will contrast the next generation Global Navigation Satellite System(GNSS). To reinforce GPS for Asia, JAXA (Japan Aerospace Exploration Agency) and NEC TOSHIBA Space System, Ltd. are now arranging to launch the QZSS (Quasi-Zenith Satellite System). If those all Global Navigation Satellite System is incarnated, positioning accuracy improve increasingly. But there are many problems to use GNSS various kinds of frequency and modulation, such as difficulty in circuit design. Currently, most of commercial GPS receivers consist of a radio frequency (RF) front-end, an Application Specific Integrated Circuit (ASIC) or FPGA (Field Programmable Gate Array) for signal processing, and CPU for higher layer functions. However, to make ASIC based receivers to correspond other GNSS signal, almost circuit design may start a fresh. In case of FPGA based receivers, redesign signal processing area in FPGA if possible. ASIC based receiver's design flexibility is very constrained by an ASIC that is hardware with predefined tracking channels, correlator and control characteristics. So software based GNSS receiver is suitable for the next generation GNSS receiver. Software based GNSS receivers are those that implement signal acquisition and tracking process not in hardware but in software. In software based receivers, corresponding to other frequency and modulation is only to add software function and adapte to the frequency. However, software based receivers have common problem with processing speed. In result, it influence TTFF (Time to First Fix) at online operation. This time, we examined fast acquisition method, using new parameter when performing Inverse FFT (IFFT). The parameters are variable by acquisition results such as Signal Noise Ratio (SNR), C/N_0.

At first, receiver structure and data collection hardware will be present in Section 2. Secondly, the different between our methods to conventional method will be described in Section 3. Thirdly, experiment method and the result will be discussed in Section 4. Finally, the conclusion will be given in Section 5.

2. Software Based GPS Receiver

2.1 Structure of Software Based GPS Receiver

Software based GNSS receivers is composed of a RF front-end to amplify and down convert input radio frequency (RF) level signal to intermediate frequency (IF) level and an analog-to-digital converter (ADC) to convert the input signal into digital data at the earliest possible stage in the receiver.

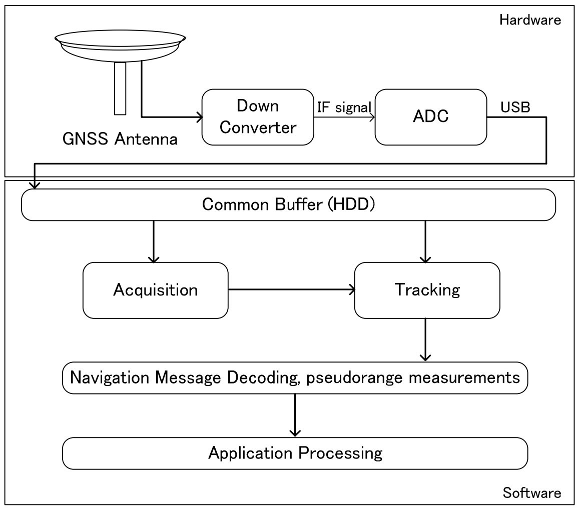

Figure1. A general structure of software based GPS receiver

General software based GNSS receivers amplify input signal data to proper amplitude and down convert to desired output frequency (IF) at first. Secondly, convert analog IF signal to digital signal data. The antenna, RF front-end and ADC are the hardware that used in software-based GNSS receivers. After these processes, the digital data are transmitted to host PC using USB interface and software is used to process. Acquisition is the first process in software based GNSS receivers. It is used to find a certain GPS satellite signal. The tracking is used to find the code phase transition of the navigation data. Ephemeris data and pseudorange measurements can be obtained from navigation data. Finally, the user position, velocity, and time can be calculated. Figure1 illustrates a general structure of software defined GNSS receiver.

Receiver type	PC based
Signal Sampling	IF sampling
IF	15.42MHz
Sampling Frequency	2MHz-20MHz (configurable step size of 1KHz)
Acquisition	FFT approach
Code Tracking	DLL
Carrier Tracking	2nd order PLL

Table1. Characteristic of Prototype Receiver

Table1 summarizes the characteristic of our prototype software based GNSS receiver. The GPS L1 C/A code signals are amplified and down converted from 1575.42MHz to 15.42MHz, and sampled in 2MS/s to 20MS/s (configurable at step size of 1kS/s) using GPS Signal Tap manufactured by Accord Software and Systems, Pvt. Ltd. The signal samples can be processed in real-time and stored to the hard disk for post processing.

2.2 GPS L1 C/A code Acquisition

As mentioned in Section2.1, acquisition algorithm is used to determine each satellite's C/A code phase and doppler frequency. In this section, Fast Fourier Transform (FFT) approach will be described.

The FFT approach performs circular convolution in the frequency domain. The Discrete Fourier Transform (DFT) and its inverse (IDFT) are used to calculate.

$$R[m] = F^{-1}(F(x[n] \cdot CAR[n]) \cdot F(CA[n])^{*}) \qquad (1)$$

Where F and F^{-1} are FFT and inverse FFT, CAR is locally generated carrier.

The non-coherent correlator in frequency domain can be adopted to the acquisition of GPS signals as shown in Figure2.

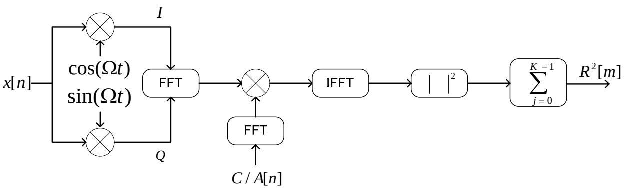

Figure2. Noncoherent Correlator in Frequency Domain

The input signal is mixed with locally generated carrier to split into inphase(I) and quadrature phase(Q). I and Q components are used as real and imaginary inputs when performing DFT. Then, maltiply complex conjugate of the result by DFT of C/A code. The results are accumulated incoherently (noncoherent integration). The Fast Fourier Transform algorithm is used to implement the DFT and IDFT, since this acquisition method called FFT approach.

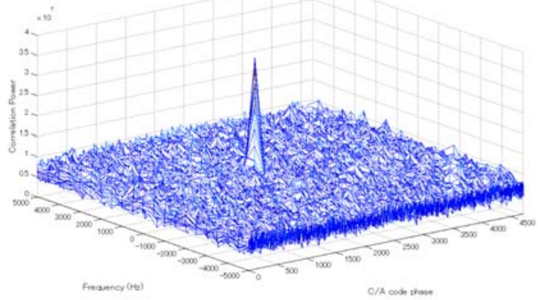

Figure 3. Correlation Matrix of SV 7

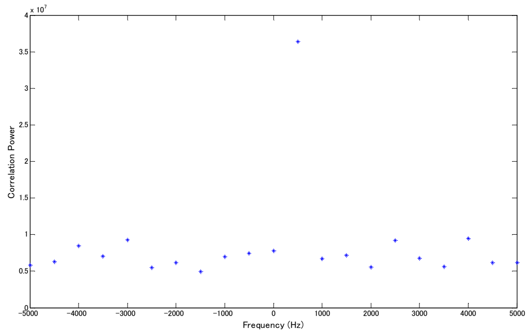

Figure 4. Frequency Components of SV 7

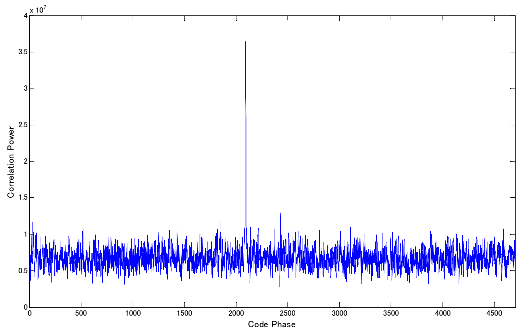

Figure 5. Begging of C/A code of SV 7

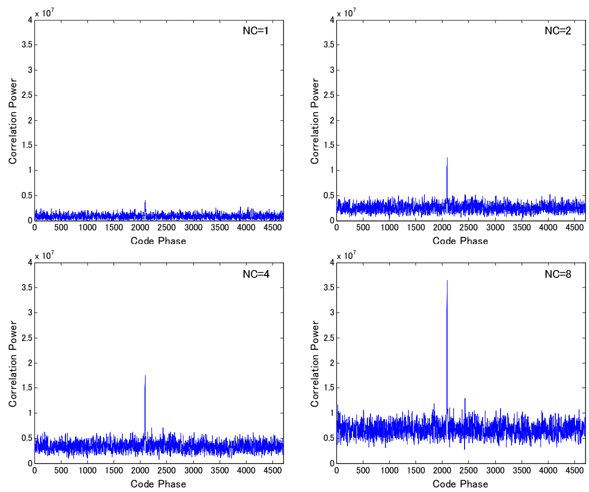

Figure 6. The effect of Noncoherent integration

Figure 3, 4, 5 show the results of acquisition using FFT approach. All the results are SV 7. Figure 3 is correlation matrix. It represents the C/A code phase and doppler frequency. After the circular convolution, C/A code phase is 2096 and doppler frequency is 500Hz.

The amplitude of each 21 frequency components of SV 7 separated by 1 KHz are shown in figure 5. Figure 6 show how the SNR increase by using noncoherent integration. In this case, we use 16ms period of data. (NC represents integration time.)

2.3 GPS Signal Tracking

Once a signal is acquired, the signal must be tracked in order to obtain the navigation data. The tracking program uses two parameters obrained from the acquisition process: the beginning of the C/A code period and the carrier frequency of input signal (Doppler Frequency). Two loops are needed to track on GPS signal. One loop is often referred to as code loop, which tracks the C/A code. The other one is phase locked loop, which tracks the carrier frequency of the down converted input signal. These two loops must be coupled together. Tracking block diagram is shown in Figure 7.

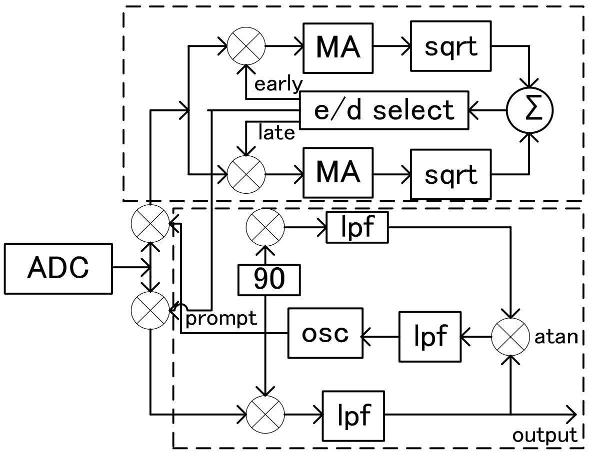

Figure7. Tracking Block Diagram

The code loop uses three locally generated C/A code (a prompt, an early, a late) to track the C/A code of the input signal. The early and late codes are the prompt code shifted a few samples to the right and left, respectively. The prompt code is applied to digitized the input signal and strips the C/A code from the input signal. The output will be a continuous wave signal with phase transition caused only the navigation data. This signal is applied to the input of the carrier loop.

The output from the carrier loop is a cw signal with the carrier frequency of the input signal. This signal is used to strip the carrier from the digitized input signal. The output is a signal with only C/A code and no carrier frequency, which is applied to the input of the code loop.

3. Another parameter for Acquisition

In this method, a parameter which determines length of IDFT is used. Using this parameter, process of acquisition was speedup making use of the characteristics of DFT in almost cases.

This parameter can be a value from 1 to n/200, where n is the number of data points in 2ms. The effect of parameter is not only speed, but the Signal to Noise Ratio (SNR) become higher in certain cases. It is because the number of components that contain only noise decrease, and be able to detect code phase clearly. SNR is set up by formula (2).

$$SNR = 10\log\left(\frac{P_s}{P_n}\right) \qquad (2)$$

Where P_s and P_n are power of signal and noise.

DFT characteristic is shown in formula (3).

$$DFT = \frac{1}{N}\sum_{k=0}^{N-1} x_k \left(e^{-j\frac{2\pi}{N}}\right)^{kl} = \frac{1}{N}\sum_{k=0}^{N-1} x_k \left\{\cos\left(\frac{2\pi kl}{N}\right) - j\sin\left(\frac{2\pi kl}{N}\right)\right\}^{kl} \qquad (3)$$

Where x is IF data, N is number of samples.

Formula (3) has periodicity, that the reason of being able to convolve. Usually, DFT can calculate 2^n in higher speed than other length. (Figure 8) If this parameter is used, the length of IDFT becomes variable, the length can be adjustable which can do fast operation

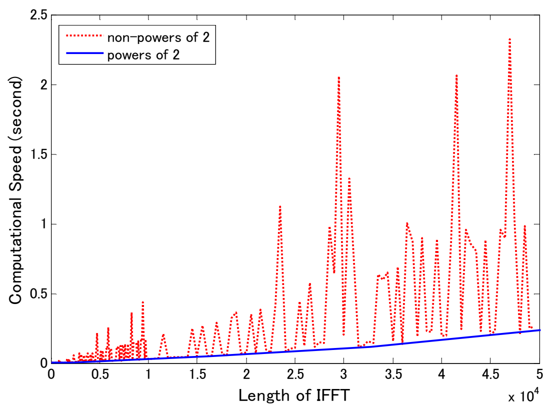

Figure8. DFT calculation Speed

4. Experiment and the Results

To verify this technique, IF data was acquired and examined under two situations, static and a moving body. The parameter was changed success was determined by the abiaty to track and obtain lock on the GPS signal within one second. Formula (4) was used to lock determination.

$$\frac{\sum I^2 - \sum Q^2}{\sum I^2 + \sum Q^2} \qquad (4)$$

Where I is the In-phase component, Q is the Quadrature phase. Each component is added individually for 20ms.

4.1 Static

A NovAtel GPS702 antenna was set up on rooftop of a five story high building to acquire IF data in the static state.

Date	2006/8/11 8:21
Data Length	15min
Situation	Static
IF	15.42MHz
Sampling Frequency	4.7MHz
IF Bandwidth	2MHz
Reference Clock	80MHz

Table2. Static Collection Data Details

Figure 8. The environment of data collection

Data collection was in a low multipath environment. There were no tall reflective structions in the surrounding area. This also meant excellent satellite visibility. A sky chart seen from the antenna is shown in Figure8. The acquisition data was from from 8:21 to 8:36 of 2007/8/11(UTC). (Table 2), and the sky chart at that time is shown in Figure 9.

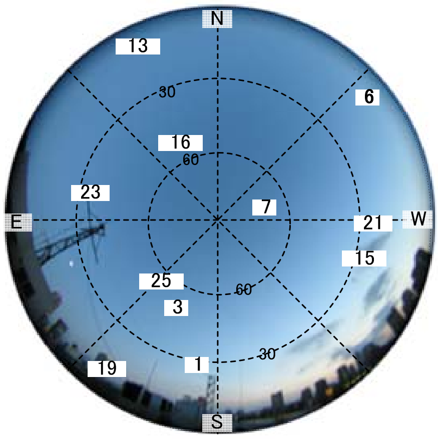

Figure 9. The sky chart at 2007/8/11 8:21 (UTC)

Success rates for high elevation satellites were signficantly better than satellites with elevations of 15 degrees or lower. Satellites below 15 degrees had a success rate of only 30%. This may be due to the various noises present in low elevation satellite signals.

Value	Length of IFFT	Success Rate (%)
1	9400	91.04
2	4700	88.96
10	940	86.72
20	470	76.46
30	313	68.44
40	235	62.51
50	188	59.82
60	156	69.21
70	134	58.34
80	117	62.05
90	104	39.97
100	94	36.62

Table3. Success Rate (Num. of SV=11, Num. of trial = 30)

When parameter values of 10 or less were used, the results did not show difference compared of the case where the parameter was one. (Parameter had no bad effect) When the value of the parameter was changed more, clear deterioration was confirmed. The differences between each parameter value are shown in Table 3. This shows that parameters values up to ten are effective only for code phase resolution.

4.2 Kinematic

Kinematic data was acquired in an urban area in Tokyo. Compared with the case of static data collection, cycle slips and data loss happen frequently, and positioning in an usual GPS receiver is very difficult situation. Under such a situation, conventional receivers usually continually attemps to re-acquire. However, because continuing reception is very difficult, most of time positioings in not possible. The signal is interrupted before the pseudorange used for the positioning is determined because the re-acquisition is too slow. Better performance can be exepted under such situation in a real-time software receiver with Fast Fourier Transform as the base technique. Data acquisition was done five times, and acquired while moving in a different respectively place. (Figure 10)

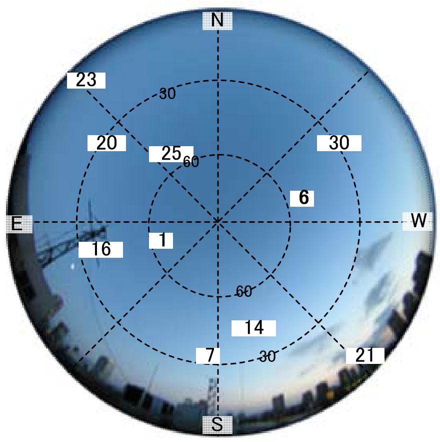

Figure 10. Sky Chart at 2007/08/28 5:35 (UTC)

Value	Length of IFFT	Success Rate (%)	Average Num. of SV
1	9400	61.54	10
2	4700	74.29	7.25
10	940	79.31	8.75
20	470	63.33	7.5
30	313	66.67	5.25
40	235	55.00	5
50	188	57.14	3.5
60	156	50.00	3.33
70	134	54.55	2.75
80	117	80.00	2.5
90	104	66.67	1.5
100	94	52.19	1.1

Table4. Success Rate (Num. of trial = 30)

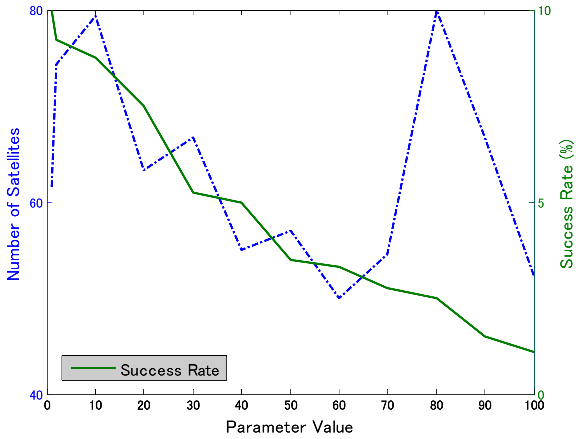

Figure 11. Relation of Num. of Satellites and Success Rate

As shown in Figure 11, ten satellites were successfully tracked when the parameter was one. However, the success rate decreases as the parameter value increases. The success rate suddenly increases when the parameter value is around 80. It is concluded that only parameter values of less than 20 have practical use.

5. Conclusion

This technique was examined with the data of plural situations, clear difference appeared in the success of acquisition. It fails in acquisition of low elevation satellite signal that contains various noises because the resolution of code phase decreased.

However, after the success ratio decreasing largely value exceeding 15, from the fact that parameter can be set freely inside the range, adjusting to sampling frequency, if is worthy of optimumly calculation length of benchmark and DFT as shown in Figure8 or 2^n at close value, high speed operation becomes possible.

Future works are to succeed in acquiring even with the satellite of low elevation and to shorten until lock on the GPS signal at tracking stage. If that actualizes, it connect directly to shortening TTFF (Time To First Fix) in the real time software receiver.

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