The Development of Modularized Post Processing GPS Software Receiving Platform using MATLAB Simulink

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Abstract

Modularized GPS software defined radio (SDR) has many advantages of applying and modifying algorithm. Hardware based GPS receiver uses many hardware parts (such as RF front, correlators, CPU and other peripherals) that process tracked signal and navigation data to calculate user position, while SDR uses software modules, which run on general purpose CPU platform or embedded DSP. SDR does not have to change hardware part and is not limited by hardware capability when new processing algorithm is applied. The weakness of SDR is that software correlation takes lots of processing time. However, in these days the evolution of processing power of MPU and DSP leads the competitiveness of SDR against the hardware GPS receiver. This paper shows a study of modulization of GPS software platform and it presents development of the GNSS software platform using MATLAB Simulink™. We focus on post processing SDR platform which is usually adapted in research area. The main functions of SDR are GPS signal acquisition, signal tracking, decoding navigation data and calculating stand alone user position from stored data that was down converted and sampled intermediate frequency (IF) data. Each module of SDR platform is categorized by function for applicability for applying for other frequency and GPS signal easily. The developed software platform is tested using stored data which is down-converted and sampled IF data file. The test results present that the software platform calculates user position properly.

Key Word : Software Defined Radio, SGR, GPS, modulization

Introduction

Hardware based GPS receiver is consisted of RF parts, correlators and a CPU which are adapted to track signal, to process navigation data and to calculate user position. However, SDR uses software modules that have the same functions as hardware parts except for RF parts. The modules of SDR run on high performance general purpose CPU platform. It is very convenient and efficient to modify algorithm of receiver architecture and to revise the software simply without changing some hardware parts. SDR has advantages that it can be easily applied to not only GPS but also other GNSS signal by simple software modification. SDR gets more and more powers in competition with hardware based GPS receiver in bottom of the rapid improvement of

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MPU and DPS's ability. This paper presents studies about modulization of GPS software platform and development using MATLAB. We explain characteristics and functions of each SDR's module first, and then discuss about experiment results which are processed with IF down converted and sampled live signal file.

Structure of SDR

Structure

The final output of GPS software receiving platform is user position using C/A code from IF down converted and sampled data which were saved in mass storage. The main functions of this platform are consists of three parts: signal acquisition part, signal tracking part, and calculating navigation data part. Standalone position comes from calculating using pseudoranges which are obtained from C/A code tracking result. The processing unit is 1ms length of IF down converted and sampled GPS signal data that is the same as one period of C/A code length.

Signal acquisition module

In this research, we use parallel search algorithm for signal acquisition, instead of serial search algorithm which is usually adapted in hardware based receiver [2]. In parallel acquisition algorithm, 1ms sampled data are loaded on memory from IF data file, and then the data are processed through Discrete Fourier Transform (DFT) or Fast Fourier Transform (FFT) to search code delay. Doppler search bin is set to 500 Hz. The total searching range is set from -5 to +5 kHz for land mobile user, from -10 to +10 kHz for aviation user. In parallel Doppler search algorithm, the resolution of detected code phase depends on the sampling frequency rate.

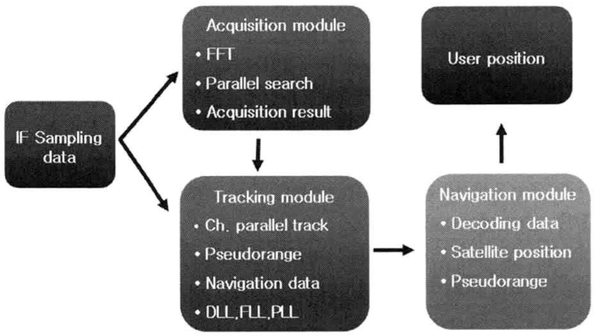

Fig. 1. The structure of SDR software platform categorized by function

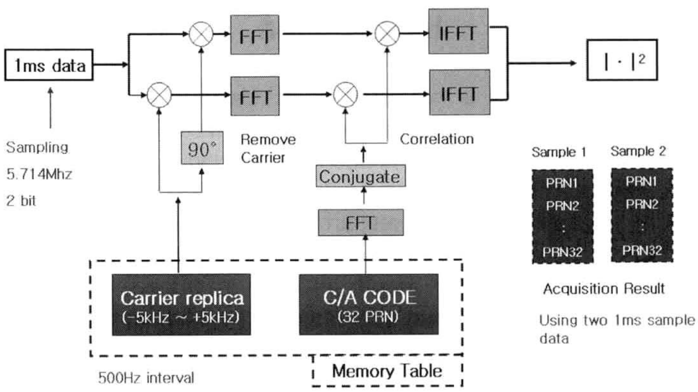

Fig. 2. Block diagram of signal acquisition concept

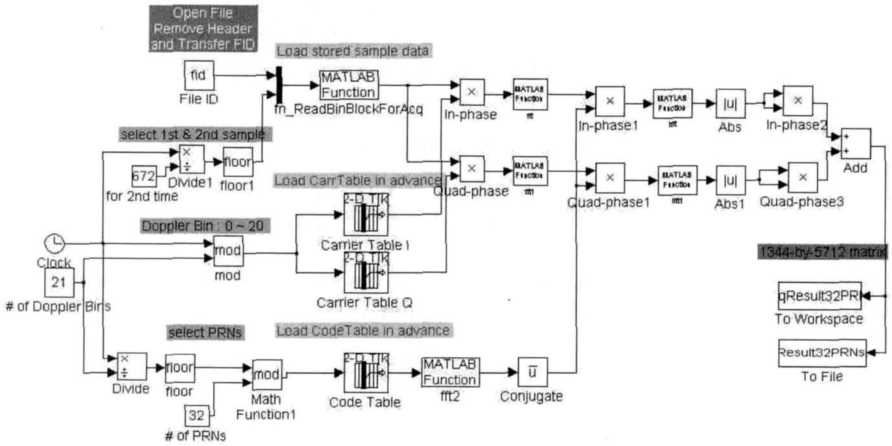

Fig. 3. Block diagram of signal acquisition concept

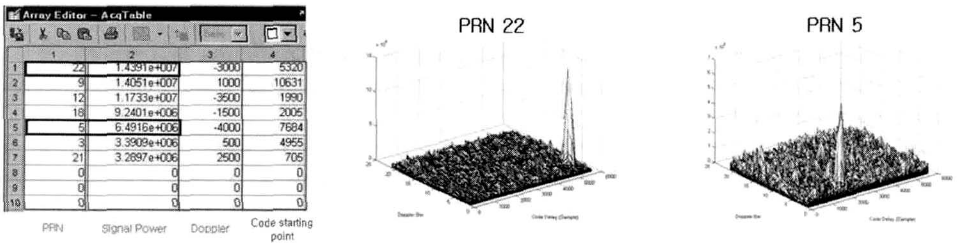

Fig. 4. Signal searching result in Doppler and code bin

Fig 2 shows the conceptual diagram of signal acquisition module. The acquisition module contains a look-up table. The FFT results of carrier and C/A code are stored in loop-up table with 1ms unit to save calculation time. The details of the algorithm are as followed depicts. First, it multiplies the stored GPS signal by carrier replica for carrier wipe-off. And next, it multiplies Fourier transformed C/A code by the carrier wipe off data. Then, invert-FFT result of the multiplied data which is same as convolution of received data and replica data in time domain is obtained. The final result is the square summed of I_phase and Q_phase for detecting GPS signal. If the result is larger than threshold then the allotted GPS signal is acquired.

Fig 3 shows the implementation of signal acquisition modules with Simulink™. The blocks are consists of look up table, FFT processing block, invert FFT processing block and some control function blocks. This module starts processing with selection of Doppler and PRN numbers. And it loads stored data and tables of FFT processed carrier and C/A code data. The next MATLAB function blocks are FFT and IFFT algorithm and the last is related with square sum function.

The test results of GPS signal acquisition are presented in Fig 4. The acquisition module found out 7 satellites in the received signal, search is complete for code delay and Doppler bin. The right figures show the search result plots of PRN 22 and PRN 5. There are 21 bins in Doppler and 2046 bins in code delay search. Only one intersection of two axes has peak value as we expected.

Signal tracking module

The signal tracking module starts its function using initial satellite signal information which is from signal acquisition module. It tracks code delay more precisely than acquisition module. We adopts same signal tracking algorithm which is used in hardware based receiver [3]. Each tracking channel has six correlators to get early, prompt, late correlation for each I-phase and Q-phase. 1ms length of stored sample data is used for each tracking process step. The tracking module's parameters, such as chip spacing, loop filter's order, band width and update rate, are flexible, therefore they could be changed easily.

DLL is implemented with first order loop and the discriminator uses next equation (1) [4].

$$D_{DLL} = \frac{1}{2}\frac{\sum(I_E^2+Q_E^2)-\sum(I_L^2+Q_L^2)}{\sum(I_E^2+Q_E^2)+\sum(I_L^2+Q_L^2)} \quad (1)$$

FLL is implemented with second order loop; the discriminator output is determined by the Cross product. The discriminator is presented in equation (2).

$$D_{FLL} = \frac{I_{p1} \circ Q_{p2} - I_{p2} \circ Q_{p1}}{t_2 - t_1} \quad (2)$$

PLL is implemented with second order loop and the discriminator uses the output value of the equation (3).

$$D_{PLL} = \tan^{-1}\left(\frac{Q_p}{I_p}\right) \quad (3)$$

The tracking module processes its function using acquisition results and stored GPS sample data at the start. Each tracking channel needs acquisition results which are PRN number, code delay value and Doppler frequency.

Output of discriminator is used for tracking loop feedback as input, and stored in memory for navigation module can be used. Pseudo range is calculated using a sample point value of the zero code phase in the 1ms length of sample data. The pseudo range is relative value among PRN channels.

Fig 5 shows the upper hierarchy view of tracking module that has identical eight tracking channels. Each channel can be disabled when the PRN is not assigned or the maximum number of acquired channels is limited by user setting. The upper hierarchy is divided into four parts. Part [A] is initial setting of tracking module; it manages the function parameter settings like EML chip spacing and loop filter parameters. Part [B] is storage section where signal tracking results are saved. And part [C] is initial value part that sets initial parameters of each channel for signal acquisition result transferred from signal acquisition module. The main tracking function is in part [D].

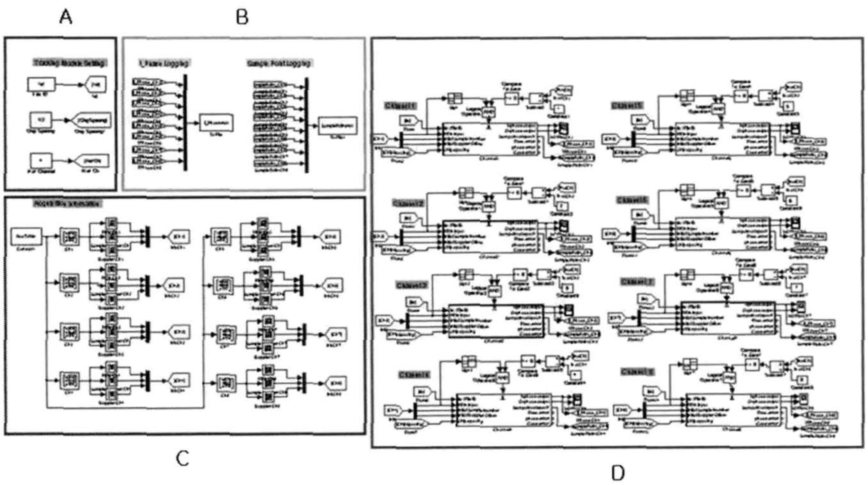

Fig. 5. Upper hierarchy view of signal tracking module structure implemented using Simulink™

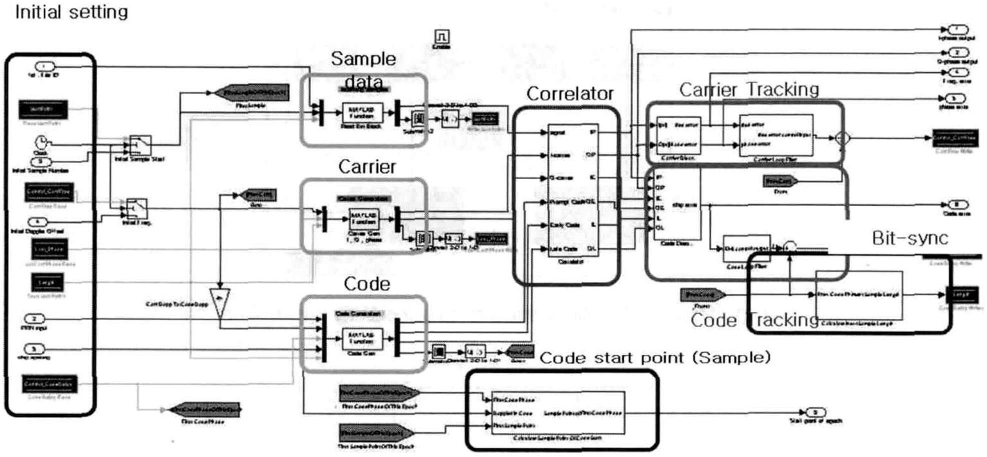

Fig. 6. Lower hierarchy view of signal tracking module implemented with Simulink™

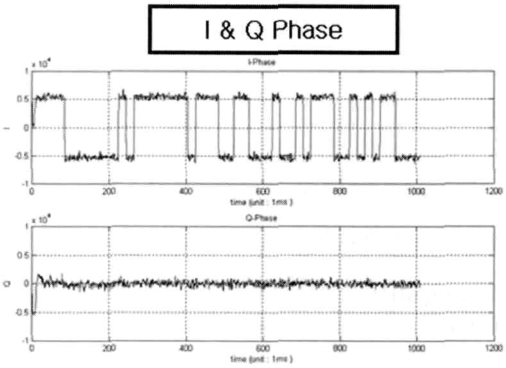

Fig. 7. I_phase plot and Q_phase plot. I_phase transits from -1 to 1

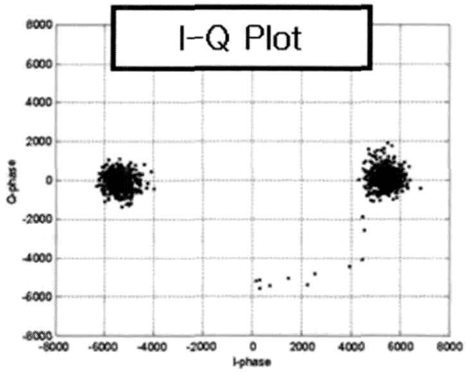

Fig. 8. 2D plot of I_phase and Q_phase

Fig 6 shows the lower hierarchy view of each tracking channel module which contains correlators, code tracker, carrier tracker and look-up tables. The tracking module channel needs file ID, PRN, Sample Number (The point where each PRN's code phase is zero in each 1ms sample data), Doppler frequency, chip spacing as input. Outputs of each tracking channel are tracking result information: I, Q phase correlation value, code phase zero point in 1ms data (start point of C/A code period) [1], filtered carrier frequency and phase discriminator output, and code phase discriminator output.

The test result of tracking processing is presented in Fig 7 and Fig 8. I_phase and Q_phase are dependent. If we want to track the signal properly, the absolute value of I_phase must be maximized and the Q_phase must be minimized. I_phase sign is switched by the data bit transition. This plots show that the tracking module figure out I_phase , Q_phase value, and the detection of I_phase transition properly.

Navigation module

The navigation module consists of two different parts: navigation data decoding part and calculating pseudo range part. The algorithm flow chart of the navigation module is presented in Fig 9. The upper section of diagram shows the navigation decoding part and the lower section shows pseudorange calculating part. The upper part decodes the navigation message using

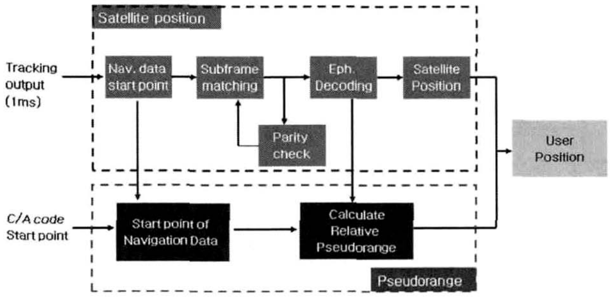

Fig. 9. Navigation module processing algorithm

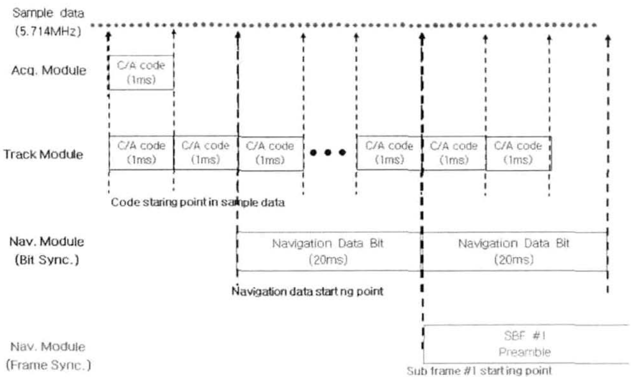

Fig. 10. Concept of relative pseudorange using sub frame starting point

I_phase transition value. We can get GPS time and navigation data like ephemeris from decoded data bit and calculate satellite position using it. Finally, the pseudorange part calculates user position with satellite position and relative pseudo range information.

In our research, we use relative pseudo range for each satellite [2]. The relative pseudorange means the range from time difference between first sub frame arrivals of different satellite signal. We can calculate relative pseudorange by using this difference. The detailed relative pseudorange concept is presented in Fig 10. The tracking module tracks GPS signal to detect and synch 1ms of C/A code, navigation bit and sub frame.

The GPS navigation message is broadcasted in 50Hz, thus 1ms length of 20 correlation values make up one message bit. In other words, 20 I_phase values are needed to restore one navigation message. The restored navigation message is decoded by algorithm in ICD-GPS definition.

The navigation module implemented using Simulink™ is presented in Fig 11. It has three main parts. The navigation module uses In-phase correlation value and code phase zero point as input parameters to calculate user position. These values are transferred from signal tracking module with the name of 'I_phase' and 'SamplePoint'. Tracking module decode the navigation data :ephemeris data, starting point of navigation bit change(Cross Point) and starting point of first sub-frame's navigation bit (PT1). Detailed function description of each module is listed on Table 1.

Table 1. Description of navigation module's three main parts

fn_CalcRho	Data message decoding Calculate the relative pseudo range
fn_CalcRhoSat	Calculate the signal transmitted time Calculate the satellite's position
userpos	Calculate the user position

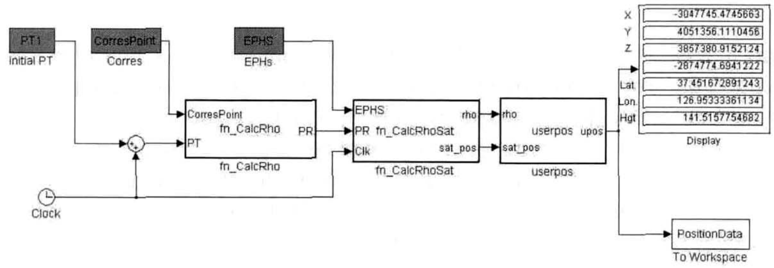

Fig. 11. Navigation module using Simulink™

Test result

The SDR platform is tested using stored sample data which are sampled at 4.1304 MHz rate with 2 bits quantized. The receiver's antenna is fixed in a static point and the user position is calculated at 50 Hz frequency. Fig 12 shows the processing result of SDR. The upper plot displays relative user position in 3D. Reference zero point is the true antenna position. The down left plot shows user position in 2D with EN position system. The true position is spotted in red circle and the down right plot presents user's height versus time flows.

The test result is compared with true value that is measured from conventional receiver. We assumed it is true value. The comparison result between the tested position from SDR platform and true position value is listed on Table 2. The bias in east direction is -3.9m and the standard deviation is 5.4m. The bias in north direction is 4.2 m and the standard deviation is 5.0m. The bias and standard deviation in upper direction is much large than east and north. The bias of upper direction is 12.9m and standard deviation is 30.2m.

The user position is calculated using smoothed raw pseudorange, Ionospheric error compensation and troposheric error compensation. However other position filtering scheme is not adopted. From these figures, plots and tables of the test result, we can suppose that the developed SDR platform calculates user position properly.

Table 2. Description of navigation module's three main parts

Direction	Bias (m)	STD (m)
East	-3.9	5.4
North	4.2	5.0
Up	12.9	30.2

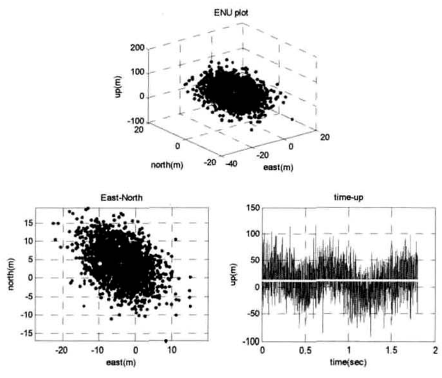

Fig. 12. User position is plotted in ENU, EN coordinate system and heigth in time domain

Conclusions

In this paper, it shows how to modulate GPS software receiving platform and presents GPS software receiving platform development using Simulink™. The developed post processing GPS software receiving platform calculates user position using C/A code from IF down converted and sampled GPS data file. All functions of SDR module are constructed independently to apply modification and adaptation easily. The test results show that the navigation solution is properly solved with sample GPS data file. This research is a first step to develop multi frequency and multi-purpose GNSS receiver. We suppose that this research is a cornerstone to develop next generation GNSS SDR. With this research the integrated GNSS receiver can develop efficiently in GPS software receiving platform.

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