DESIGN OF A HIGH DYNAMIC GPS RECEIVER

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ABSTRACT

High dynamic and multi-channel digital GPS receiver can handle the signals with high dynamic range, low S/N ratio and refresh data quickly. A hardware design of high dynamic GPS digital receiver is given. Based on analysis of the effect that high dynamic movement makes on the receiving signals, a scheme of fast-acquisition high dynamic GPS receiver is presented. Exact reckoning of the orbit parameters and the satellite clock parameters are integrated with appropriate algorithms. A DDLL is used to precisely estimate the C/A code delay, a CPAFC loop and a Costas loop to precisely estimate the carrier frequency and phase. The DDLL is assisted with carrier phase. The experimental results show that the receiver meets the design request.

KEYWORDS

Global Position System (GPS), high dynamic, digital signal processing, receiver, acquisition.

INTRODUCTION

When the receiver does not store almanac or there is no available almanac because of not working for a long time, the receiver will go through a “cold start”. When the almanac prediction error is not tolerable, the receiver will expend a long time to acquire

GPS signals, get ephemeris, then get the position exactly. However, exact reckoning of the orbit parameters, the satellite clock parameters and the receiver clock parameters, integrated with appropriate algorithm can efficiently shorten the positioning time for GPS receivers.

In order to receive the signals on high dynamic conditions, we must carefully design the soft loop part in the module of digital signal processing of the receiver, which is one of the key parts of a high dynamic receiver.

DETERMINING THE RECEIVER TIME

Because the time error of the clock $\Delta t(t)$ can be expressed by a polynomial whose independent variable is the time t, $\Delta t(t)$ can be spread at t_1 [1].

$$\Delta t_t = \Delta t_{t_1} + \delta(t - t_1) + \frac{1}{2}\alpha(t - t_1)^2 \quad (1)$$

Where, δ is the error of the frequency drift, α is the crystal aging velocity, that is gotten at t_1.

After getting the time error, we can determine the receiver time. The GPS time parameters of the receiver include week number of the current GPS time WN (current week number) and Z count, that is, TOW count. Because the navigation data express week number by 10 bits, the largest number of week that expressed by the 10 bits is 1024, which is ambiguous.

For reckoning the Greenwich time of observation point with the week counts of GPS time, we must calculate the true week counts integrated with other parameters. The week number of the 10 bits can express 1999.8.21.23.59.59, so the receiver must subtract 1024 from the weeks that derived from the recent Greenwich time of observation dot. Because of the leap second, there is 13 seconds' difference between

UTC time and GPS time after 1998.12.31.59.59. So the week number of the 10 bits can express 1999.8.21.23.59.47.At the same time, time conversion from Greenwich time to GPS time must consider the time zone of the receiver.

$$WN = \frac{(y-1980)\times 365 + doy[m-1] + d + D_1 - 6}{7} - 1024 \quad (2)$$

$$d1 = (y-1980)\times 365 + doy[m-1] + d + D_1 - 6$$

$$D_1 = \frac{y-1980}{4} + 1 \qquad (y-1980)\%4 = 0 \text{ or } m \le 2 \text{, then } D_1 - 1$$

$$t_{sec} = (d1\%7)\times 86400 + (hh - TimeZone)\times 3600 + mm\times 60 + ss + 13 \quad (3)$$

if $t_{sec} \le 0$, then $WN - 1$ and $t_{sec} = t_{sec} + 604800$

$$Z\_Count = INT[t_{sec}/6] + 1 \quad (4)$$

Where, $y, \mathrm{m}, \mathrm{d}, \mathrm{hh}, \mathrm{mm}, \mathrm{ss}$ is the year, month, day, hour, minute, second of the simulate time; t_{sec} is the second number at the beginning of the GPS week epoch. % is the modular arithmetic; doy[12] = {0,31,59,90,120,151,181,212,243,273,304,334}; TimeZone is the time zone of the simulator.

DOPPLER SHIFT COMPONENTS OF THE RECEIVER

Our receiver utilizes GP2010 and GP2021 of Zarlink Semiconductor. The frequency of the satellites signals is firstly down converted to the 4.308 MHZ intermediate frequency signal. Then the intermediate frequency signal is under-sampled by a 5.715 MHZ clock and output the digital signals. The digital signals are expressed:

$$r(t) = \sum_{i=1}^{M} A_i C_i[(1-\frac{f_{id}}{1540})(kT_s - \tau_i)] D_i[(1-\frac{f_{id}}{31508400})(kT_s - \tau_i)] \sin[2\pi(f_1 - f_{id})kT_s - \phi_i] + n(t) \quad (5)$$

where A_i is the signals intensity, $D_i(t)$ is the ephemeris data of the I satellite , $C_i(t)$ is the spreading code of the i satellite, τ_i is the delay value of satellites signals transmitted, $f_0 = 1575.42MHz$, ϕ_i is the phase of the satellites signals.

$T_s = \frac{1}{5.715M}$, f_1=1.405MHZ, M is the number of the visible satellites.

$$f_{id} = \Delta f + f_{rec} + f_s \tag{6}$$

f_{rec} is the frequency error that the frequency drift of the receiver clock brings, f_s is the frequency drift of the GPS satellite, Δf is the Doppler shift of the GPS signals that is lead by relative movement between GPS satellite and the receiver,

$$\Delta f = \Delta f_{sv} + \Delta f_{rec} \tag{7}$$

Where, Δf_{sv} is the Doppler shift of the GPS signals that are lead by relative movement between GPS satellites and the immobile receiver along the direction that the GPS signal transmit, Δf_{rec} is the Doppler shift of the GPS signals that are lead by relative movement of the mobile receiver along the direction that the GPS signal transmit.

Referring to the GPS-ICD-200C Interface Control Document, we can get the f_s

$$af_{1_t} = af_{1_{t1}} + af_2(t - t_1) \tag{8}$$

Where, af_1, af_2 are the clock parameters of the navigation data of the GPS satellite[2].

$$f_s = af_{1_t} \times f_0 \tag{9}$$

According to the orbit parameters of the GPS satellites in the ephemeris of t_1, we can get the orbit parameters of the GPS satellites of t. Supposing that six correction parameters are all zero, we also get the almanac of t[3]. Then we can get the position and velocity of the GPS satellite at t. Considering the position of the receiver, we can get Δf_{sv} of t.

The receiver is stationary at the observation time, here Δf_{rec}=0. Synchronously we can get Δf_{sv}^j of the i satellite, f_{rec}^j of the i satellite at the observation time is got

$$f_{rec}^{j} = f_{id}^{j} - \Delta f_{sv}^{j} - f_{s}^{j} \tag{10}$$

THE DESIGNING OF THE LOOP OF THE RECEIVER

We adopt the serial-parallel combined technology and MLE technology to realize the fast-acquisition function. The coarse estimation of C/A code delay and Doppler frequency of carrier are carried out through MLE. The precise estimation of C/A code delay is achieved through DDLL. The precise frequency estimation is realized through a CPAFC loop and a Costas loop. And the DDLL is assisted with carrier phase. Finally the navigation data are demodulated through the Costas loop.

When the receiver is in the state of precise code and carrier tracking, for the cross product loop, we can realize frequency tracking. The discriminator is

$$f_k = I(k-1)Q(k)-I(k)Q(k-1)= \tag{11}$$

$$0.25A^2 D(k)D(k-1)R[\varepsilon(k)][\varepsilon(k-1)]\sin c\{[\Delta f_d(k)]\cdot \pi T\}\sin c\{[\Delta f_d(k-1)]\cdot \pi T\}\sin(\phi_k - \phi_{k-1})$$

Where, A is the signals intensity, $D(k)$ is the ephemeris data, $\sin c(z) = \sin z/z$, $\Delta f_d(k)$ is the Doppler shift estimate remain. $\varepsilon(k)$ is the code phase estimate remain error. $\phi_k = \Delta f_d(k)\cdot k\pi T + \phi_0'$ is the phase of the carrier of the satellites signals. T is the correlator integral time. $\phi_k - \phi_{k-1} = \Delta f_d(k)\, \pi$ T, when $|[\Delta f_d(k)]\cdot \pi T|$ approach zero, $\sin c\{[\Delta f_d(k)]\cdot \pi T\}\sin c\{[\Delta f_d(k-1)]\cdot \pi T\}=1$, $\sin(\phi_k - \phi_{k-1}) = \phi_k - \phi_{k-1} = \Delta f_d(k)\, \pi$ T.

The filter use a 2nd order Jaffe-Rechtin filter with a bandwidth of B_{LF} , the following frequency correction terms can be derived[4]:

$$\Delta\omega = T\omega_k' + \sqrt{2}\omega_{nF} f_k$$

$$\omega_k' = \omega_{k-1}' + \omega_{nF}^2 f_k \tag{12}$$

Where T is the sampling interval of 1ms, $\omega_{nF} = 1.89 B_{LF}$.

For phase tracking and navigation data demodulation loop:

$$I' = I(k)\cos\theta_k + Q(k)\sin\theta_k \qquad Q' = Q(k)\cos\theta_k - I(k)\sin\theta_k \qquad \Delta\theta_{k+1} = \mathrm{sign}(I')Q'$$

$\Delta\theta_{k+1} \rightarrow \Delta\theta'_{k+1}$ (managed by the Jaffe-Rechtin filter)

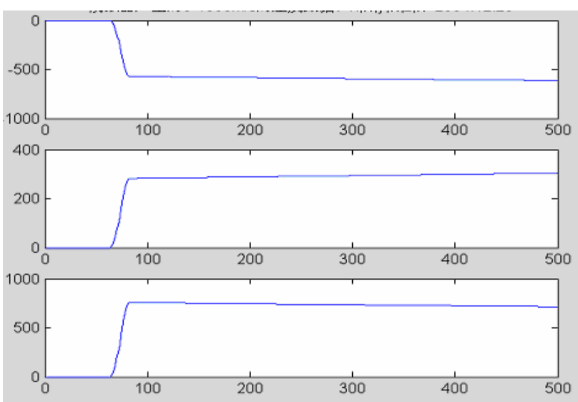
$$\theta_{k+1} = \Delta\theta'_{k+1} + \theta_k \tag{13}$$

Where, $I(k) = A\cos\phi_k$, $Q(k) = A\sin\phi_k$, $\phi_k = \Delta f_d(k) \cdot k\pi T + \phi_0'$, $A = \sqrt{I^2 + Q^2}$, I' gives a representation of the current data bit.

RESULTS OF THE EXPERIMENT

Figure 1 is a curve of the velocity of x,y,z directions of a moving vehicle varying with the time, which is generated by the simulator STR4750 from SPIRENT company.

speed(m/s)

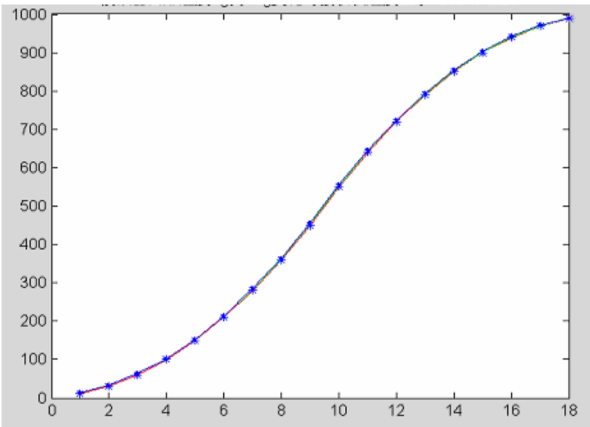


time(s)

[Fig.1]speed data(x,y,x axis) given by STR4760

Figure 2 shows the receiver velocity corresponding to the simulated maneuver with a jerk in Figure 1, where, * is the data from the simulator. The velocity of the simulated vehicle changed from 0 to 1000m/s within 18 seconds; the line with spots represents the velocity of the receiver. We can see that the line with * and the line with spots coincide with each other, which demonstrates that the receiver positions properly on the high dynamic condition with jerk of 1g/s, acceleration of 10g, velocity of 1000m/s. The velocity error can be limited to 0.8m/s.

speed(m/s)



time(s)

[Fig.2]the speed output of the receiver(acceleration time slice)

CONCLUSION

The experiments in the laboratory and the engineering application validate that the design scheme of the loop is feasible, which has achieved the performance requests of the receiver. The receiver can work with an acceleration of 12g, a jerk of 4g/s. Meanwhile, the cold start time of the receiver can be limited within 25 seconds.

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