An UKF Scheme for GPS Signal Tracking

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Abstract—Under high dynamic situation, the typical GPS carrier tracking loop cannot guarantee a reliable tracking. In this paper an improved high dynamic carrier tracking method based on unscented Kalman filter is presented, a rapid frequency traction method is adopted to ensure that the filter can convergence quickly, and joining a carrier amplitude estimation method. The U.S Jet Propulsion Laboratory high dynamic carrier model is used to test the loop tracking performance, the test results show that the method can not only pull-in and lock the carrier signal quickly in a high dynamic environment, but under the jerk of up to 100g/s which also have a continuous and precise tracking performance.

Keywords—High dynamic, GPS, Unscented Kalman Filter, Carrier tracking

I. INTRODUCTION

GPS (Global Positioning System) could provide worldwide high-precision positioning and navigation services, and it has been widely used in civilian and military fields. In high dynamic environment, due to the rapid movement of the carrier, the received signal carrier Doppler shifts very quickly over time, if use a common receiver, carrier tracking loop bandwidth should large enough to be able to tolerate such dynamic carrier frequency and phase caused by the normal fluctuations of the signal in order to ensure continuous tracking loop. However, the wider the loop bandwidth, the more frequency components of the noise is allowed to enter the loop, resulting in deterioration of the noise performance of the loop, signal tracking is also less accurate, so traditional PLL cannot be directly applied to the high dynamic receiver. To solve these problems, some scholars proposed Kalman filter or unscented Kalman filter applied to the carrier tracking loop[1-3], under the premise that an accurate establishing system model and noise statistics are known, through the filter recursive, we can obtain a more accurate estimate of the carrier phase, thereby improving the accuracy of tracking.

However the above method only tracked the frequency change, but not considering the phase changes, moreover these methods are not considered the impact of tracking loop carrier amplitude fluctuations, so the above high-dynamic model cannot completely solve the problem of optimal estimation, only can be said to be sub-optimal, it cannot be applied in practice. In this paper, a novel UKF carrier tracking method is proposed, considering the carrier amplitude fluctuation, and joined a frequency pulling method, and finally verified by simulation, and confirming the correctness of the theory loop design and tracking performance superiority.

II. JPL HIGH DYNAMIC MODEL

The indicators used to test the proposed carrier tracking loop tracking performance are based on U.S. Jet Propulsion Laboratory (JPL) defined high dynamic simulation environment [4]. The high dynamic processes for the duration is 8s, the most severe dynamic occurs in 3s-3.5s and 5.5s-6s. The two periods has amplitude of 100g/s of positive, negative jerk, during the period is the constant acceleration of 25g. High dynamic movement velocity, acceleration and jerk track of changes with time are shown in Figure 1 (a), (b) and (c), where the speed, acceleration and jerk indicators can use GPS L1 signal conversion factor 5.25Hz / (m / s) into the corresponding loop input test signal Doppler frequency and its first and second derivatives.

Applied the above model to the high dynamic GPS signal, we can get the GPS signal expression:

\[ s(t) = A[C(t_t - \tau(t))D(t_t - \tau(t))\cos[\omega_F t_0 + \theta(t_0)] + N(t_0)] \] (1)

Where A represents the signal amplitude, \(C(t)\) represents a rate of 1.023MHz pseudo-random code, \(D(t)\) is the frequency of 50Hz navigation data, \(\omega_F\) is the angular frequency of the IF signal, \(\theta\) is the receiver satellite relatively high dynamic movement of the time-varying Doppler shift caused by the carrier phase, \(N(t)\) is the transmission delay time of \(t_k\).

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III. THE UKF BASED HIGH DYNAMIC GPS CARRIER TRACKING LOOP

Since the phase of the signal changes fast in high dynamic environment, amplitude is also attenuated, the FLL assisted PLL method is likely to cause the receiver loses lock [5]. Optimal Filtering of non-causal filter can effectively resist the loss of lock. So we can use tracking method based on UKF to track high dynamic carrier signal phase [6], and applied it to the software receiver.

A. Block Diagram of the Carrier Tracking Loop

![Figure 2: Block diagram of the carrier tracking loop based on UKF](image)

Navigation data within 1ms transition does not occur change, \( I_{pr} \) and \( Q_{pr} \) is immediate accumulated value on the GPS L1, generated the local CA code divest the received signal C/A code completely [7], the expression is as follows:

\[
Q_{pr,k} = \sum [A_{i,j} \cdot CA(t_{i,j} - \tau_j) \cdot \sin(\theta_{i,j}) \cdot CA(t_{i,j} - \tau_i)]
\]

\[
I_{pr,k} = \sum [A_{i,j} \cdot CA(t_{i,j} - \tau_j) \cdot \cos(\theta_{i,j}) \cdot CA(t_{i,j} - \tau_i)]
\]

Where \( k \) and \( j \), respectively, in the first place and the time period \( t_k \) and \( t_{k+1} \) of the k-th time interval and the j-th sampling point, \( \hat{\tau}_k \) is the estimated transmission delay, \( \hat{A}_k \) is the signal amplitude of the spreading means, \( \Delta \tau_k \) is the code phase error means, \( \Delta (\cdot) \) is the CA code autocorrelation function, when \( \Delta \tau_k = 0 \) the value of \( \Delta (\Delta \tau_k) \) is 1.

If the instantaneous signal \( I_{pr,k} \) and \( Q_{pr,k} \) were sent to UKF directly, the data \( D(t) \) transition will cause the filter identify the phase of the carrier incorrectly, resulting in loss of signal. Thus, use (4) to eliminate the influence of \( D(t) \) transition.

\[
I_{pr,k}^i - Q_{pr,k}^i = \hat{A}_k^i \cdot D(t_i)^2 \cdot \Delta (\Delta \tau_k)^2 \cdot \cos(2\theta_j) + N_i
\]

\[
2 \cdot I_{pr,k}^i \cdot Q_{pr,k}^i = \hat{A}_k^i \cdot D(t_i)^2 \cdot \Delta (\Delta \tau_k)^2 \cdot \sin(2\theta_j) + N_i
\]

This tracking loop operates in half-open-loop mode, you can directly track the current carrier Doppler additional phase, rather than the traditional closed-loop phase error. UKF is used to replace the phase detector and the loop filter, so it is not associated with the scope of the discriminator and loop bandwidth, the dynamic range and tracking accuracy are increased [8].

B. Frequency Fast Pull in

The acquisition bias caused by frequency drift and residual error is generally 40 ~ 50 Hz during the signal acquisition process. Such a result, if directly used to initialize the filter, may cause the filter divergence, even if it converges, the tracking precision is also affected. An effective way is to use frequency discriminator to achieve frequency fast pull-in, with the frequency bias less than 5Hz [9].

\[
Cross(k) = I_{pr,k-1} \cdot Q_{pr,k} - I_{pr,k} \cdot Q_{pr,k-1}
\]

\[
Dot(k) = I_{pr,k-1} \cdot I_{pr,k} - Q_{pr,k} \cdot Q_{pr,k-1}
\]

\[
\Delta W_k = \frac{1}{T} \tan(2(Cross(k), Dot(k)))
\]

Where \( \Delta W_k \) is the frequency error. The above process is needed to calculate for 20 points in order to get the accurate result.
As BPSK modulation on the GPS L1 signal, there may exist inconsistent between the former and the latter \(D(t_i)\), leading to incorrect \(\Delta w_i\), but there is only one such point, which is usually the max or the min value. The singular point is removed and averaged the rest results to get the accurate \(\Delta w_i\).

C. UKF State Equation

The UKF works with mathematical models at the signal dynamics and the accumulation measurements \(I_{ps,k}\) and \(Q_{ps,k}\)\(^{10}\). The signal dynamic model describes the time evolution of important signal parameters that need to be estimated, which include the carrier phase, Doppler frequency parameters and the carrier amplitude. Here taking the signal amplitude into account is necessary. For one thing, there is a change in signal to noise ratio (SNR) during the signal propagation; for the other, not completely synchronized pseudo-code phase in the accumulation progress as Eq. (1) can also cause signal amplitude change. If UKF does not deal with these changes, they will be equivalent into the carrier phase, leading to the decreasing of tracking accuracy.

State equation of UKF is linear, expressed as

\[
S_k = \Phi S_{k-1} + Q
\]

IV. LOOP PERFORMANCE SIMULATION

The simulation conditions are as follows: C/N = 25dB/Hz, RF front-end is 2MHz, IF frequency is 1.25M, sampling rate is 7.25MHz. In the GPS signal acquisition process using the parallel data to complete 1ms FFT fast code phase and a 10ms data to complete acquisition of the carrier frequency, the phase error is one chip, the carrier frequency error is about 40Hz, using the improved algorithm to test Doppler shift, the first order Doppler frequency shift, second order Doppler frequency shift of the tracking loop respectively.

Figure 3, 4 and 5 show Doppler shift of the input signal tracking of improved UKF algorithm, they indicate that under high dynamic environment the algorithm can estimate the Doppler shift of the carrier very exactly, show a good tracking performance.
Figure 6 shows the comparison of RMSE under different CNR of the carrier phase error. The curve of the figure show that the improved UKF carrier phase tracking has significantly improved in accuracy compared to the general UKF.

As can be seen from the figure when there is a rapid frequency traction, when the tracking loop is locked, the phase error is less than 0.2 rad, and when there is no traction fast frequency tracking loop, the initial phase error can be up to 0.4 rad, initial frequency error up to 40 Hz, which can easily lead to filter divergence, then lead to loss of lock tracking loop, the frequency of rapid traction module effectively improve the dynamic environment of high tracking accuracy and reduce the probability of losing lock loop.

V. CONCLUSION

The proposed high dynamic method based on UKF carrier tracking, considering the magnitude of fluctuations on the carrier tracking loop effects, adding a frequency of rapid traction, theoretical analysis and simulation results show that the proposed method can be used in high dynamic environment for GPS signal with fast and stable frequency and phase tracking, frequency pulling effectively inhibit the rapid divergence of the filter, improve the accuracy of tracking.

REFERENCES