International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 12, December - 2017

A Novel Quasi-Open Loop Architecture for GNSS Vector Tracking Based on Collective Detection

Wantong Chen
Tianjin Key Lab for Advanced Signal Processing
Civil Aviation University of China
Tianjin 300300, People's Republic of China

Xingli Sun
School of Information and Communication Engineering
North University of China
Taiyuan 030051, People's Republic of China

***Abstract*— In past several decades, the classical closed loop architectures, such as phase locked loops and delay locked loops, have been utilized for tracking global navigation satellite system (GNSS) signals. However, in harsh environments, such as high dynamic and weak signal applications, navigation with closed loop architectures is challenging. This paper proposes a novel architecture for tracking the frequency of the incoming GNSS signal which combines the good properties of both open loop and closed loop architectures. This novel architecture is based on the collective detection technique, which is shown to be able estimate the receiver position prior to entering vector tracking loops. Since collective detection combines the information from all satellites in view to enable a direct navigation solution, it is useful to provide a rapid initialization to the position-domain navigation filter. The proposed architecture has a better robustness and accuracy.**

***Keywords*— GNSS; open loop; vector tracking; collective detection; weak signal navigation**

I. INTRODUCTION

Global Navigation Satellite System (GNSS) is the general concept used to identify a system which allows user position computation based on a constellation of satellite such as GPS, Galileo and BDS. The user computes its position from measured distances between the receiver and a set of in-view satellites. However, the relative motion of both satellites and the user causes a Doppler effect, which results in a large frequency shift in the carrier and in the code of the received signal [1]. Only an accurate tracking of the carrier frequency and Doppler shift allows the receiver to estimate the propagation time that transmitted signals take from each satellite to the receiver, thus enabling reliable estimates of position by tri-lateralization [2]. In any GNSS receiver, the acquisition stage provides an initial coarse estimation of the frequency shift, and then the subsequent tracking systems refine the coarse values of code phase and frequency and to keep track of these as the signal properties change over time. It indicates that the tracking stage contains two parts, code tracking and carrier frequency/phase tracking, which are generally implemented in the form of closed loops.

The code tracking is most often implemented as a delay lock loop (DLL) where three local codes (replicas) are generated and correlated with the incoming signal. These three replicas are referred to as the early, prompt, and late replica, respectively. The three codes are often separated by a half-chip length. The carrier wave tracking can be done in two ways: either by tracking the phase of the signal or by tracking the frequency, that is, phase lock loops (PLL) and frequency lock loops (FLL), which track respectively the phase and the frequency of the incoming carrier [2]. All these traditional GNSS signal tracking schemes are based on the scalar strategy, in which the signal of each satellite is tracked separately. For this scheme, the implementation is the relative ease, but the relevance of the signals via the receiver' position and velocity is completely ignored.

More recently, many studies have focused on vector tracking, which uses the receiver's position and velocity estimates to close the tracking loops. An extensive body of knowledge has well documented vector tracking's superiority under harsh environments such as indoor, foliage and deep urban canyons. Instead of the classic scalar-based DLL, PLL and FLL, the corresponding vector-based delay lock loops (VDLL), vector-based phase lock loops (VPLL) and vector-based frequency lock loops (VFLL) have been employed in vector-based GNSS receivers. Although a vector-based tracking loop provides significant performance improvement over traditional techniques, the benefits of vector tracking loops are still hindered by the stability problems. This is because the measurement residuals are independently estimated by discriminators for each satellite signal and the navigation feedbacks are still utilized in the form of closed loops. It is well known that the measurement error from individual discriminators increase very rapidly with the increase in attenuation and interference, thus making the performance deteriorated [3]. Moreover, because of their closed loop structure, they need a long acquisition time before attaining the loop lock, and the combination of receiver clock instability and user dynamics have to be sufficiently low in order to maintain the coherence of the received signal.

In this paper we propose an alternative solution, based on a novel quasi-open loop architecture, which relieves the stress on the vector filter in terms of stability. In the proposed architecture, an open loop tracking strategy is combined with the vector-tracking structure based on the maximum likelihood (ML) navigation solution. The benefit is that measurements are generated based on ML criterion, indicating that the performance of these measurements will asymptotically approach the Cramer-Rao lower bound. The ML navigation solution is achieved by the collective detection technique, which projects the signal power from all correlators from all satellites into the navigation domain [4]. The final navigation solution is then obtained from the point in the navigation domain that has the most power. In this way, navigation sensitivity will be superior to conventional

This project is supported by National Natural Science Foundation of China (Grant No. 61401468).

navigation solution processor, even all signals are too weak to be acquired and tracked by the traditional framework.

The rest of this contribution is organized as follows. Section II provides a brief review on the closed loop architecture to signal acquisition and tracking, including both Scalar-Based tracking loop and the Vector-Based tracking loop. Section III introduces an open loop tracking strategy and the ML navigation solution. Section IV proposes the collective detection algorithm and its assumptions. Section V elaborates on the feasible open loop tracking scheme and the final quasi-open loop architecture. Section VI verifies the correctness of architecture for GNSS vector tracking and the accuracy of coarse position solution. Section VII concludes the overall contributions of this work.

II. THE CLOSED LOOP ARCHITECTURES

A. The Scalar-Based Tracking Loop

The classical closed loop architectures, such as PLL, FLL and DLL, have been used for many years for GNSS signal tracking. These architectures are usually tracked on a satellite-by-satellite basis, indicating that the signal of each satellite is acquired and tracked individually. As is shown in Figure 1, Scalar-Based tracking loop consists of independent discriminator, loop filter and numerically controlled oscillator (NCO) for each channel.

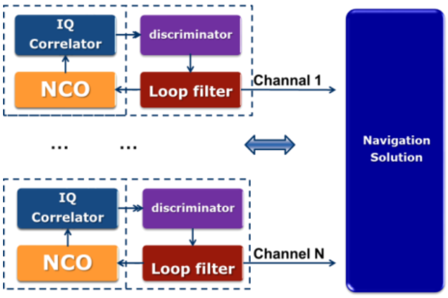

Fig.1 The architecture of Scalar-Based tracking loop

The instantaneous phase is estimated by the phase discriminator. The output of the discriminator, which is the phase error (or a function of the phase error), is then filtered by the loop filter and used as a feedback to the numerically controlled oscillator (NCO), which adjusts the frequency of the local signal (code or carrier). By this closed loop architecture, the local signal could be an almost precise replica of the input signal. As is well documented in many literatures, the loop filter is the most critical block, whose function is providing a degree of noise rejection and supporting the processing of higher order dynamics [5]. The filtered output can thus be used to drive the NCO for the signal generation. In a closed loop manner, the phase estimate of each channel is then progressively updated using the information provided by the new correlator output.

B. The Vector-Based Tracking Loop

The traditional GNSS signal tracking is based on a scalar strategy, in which the signal of each satellite is tracked separately. The benefits of this architecture is the relative ease of implementation and a level of robustness that is gained by not having one tracking channel corrupt another tracking channel [6]. However, this scalar-based tracking ignores the fact that the signals are in essence related via the receiver' position and velocity. Instead of tracking each satellite's signal separately, the Vector-Based tracking in GNSS receivers is based on the idea that all signals are ultimately related to the position and velocity of the user antenna and thus can be tracked collectively.

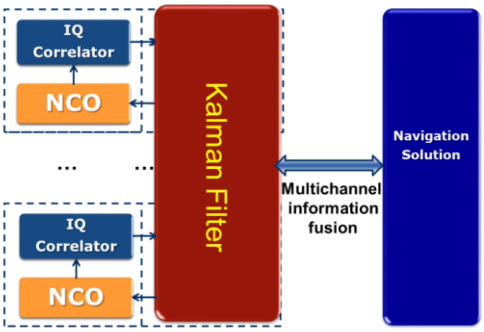

Fig.2 The architecture of Vector-Based tracking loop

As is shown in Figure 2, the code phase and Doppler of each signal are calculated by incorporating the current navigation solution (i.e., position, velocity, and time) and available ephemeris into a centralized Kalman filter and then used to drive the NCO that generate the local signals. Next, the tracking loops estimate the errors/residuals in the NCO, which are used to correct the measurements and update the navigation solution.

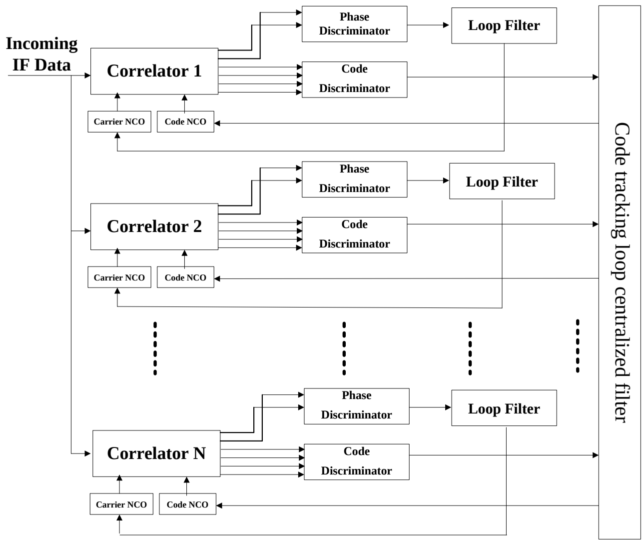

Fig.3 The architecture of VDLL

The benefit of this Vector-Based tracking loop is that the tracking errors for "low carrier-to-noise ratio" satellites can be reduced by the good satellites whose signals are accurately tracked. Because the position and velocity of the receiver can be estimated by the good satellites and they can then be used to set the signal parameters for all satellites. However, in challenging applications, the benefits of the vector tracking loops are still hindered by insufficient signal-to-noise ratio, resulting in stability problems in the local tracking loops [7]. This happens because an adequate number of "good" satellites must be available to assist the tracking of the channels with "bad" satellites. Due to the cascaded and feedback architecture, the navigation solution and tracking performance may be deteriorated by the more "bad" satellites. In the past two decades, many architectures have been reported such as

VDLL for code tracking and VFLL or VPLL for carrier tracking. Taking the VDLL as an example, individual delay lock loops are not present in it. Instead, a centralized filter is used to track the satellite signals, as is shown in Figure 3. The VDLL in general uses an extended Kalman filter (EKF) as the centralized filter for code tracking. The state vector of the EKF contains all the output of the discriminators as the elements of its state vector.

III. THE OPEN LOOP ARCHITECTURES

A.Open Loop Tracking Strategy

For the closed loop tracking strategy, the local tracking loops should be well-designed to balance processing gain, dynamic range and stability. For the challenging applications, such as for weak signal tracking and extremely high dynamic applications, the loop design procedure becomes intricate. First, the integration time is limited by the data-bit transitions and good receiver clock performance is required over the integration interval. Second, the stability and robustness are still challenging in harsh environments, for example, it is a known fact that PLLs/VPLLs are vulnerable to fading effects, typically associated with cycle slips [8]. The use of open loop architectures can solve these problems, which operate on batches of the incoming signal. That is, an input signal batch is correlated with batches of a signal replica in order to obtain an entire 3-D image of the signal, whose dimensions are the code shift, the Doppler shift, and the signal energy [9]. The open loop approach does not separate clear acquisition and tracking stages. Thus, there is no loop filter, which is replaced by the navigation solution.

B.The Maximum Likelihood Navigation Solution

The ML estimator jointly estimates receiver position and velocity, which is equivalent to a least-squares estimate which minimizes the integral:

$$\int_{T_0}^{T_0+T} \left| r(t) - \sum_{i=1}^{N} m_i(t)\, a_{i,n} e^{j(\omega_i t + \phi_{i,n})} \right|^2 dt \qquad (1)$$

where $r(t)$ is the complex-valued baseband received signal plus noise, N is the number of satellites observed, T_0 is the beginning of the captured signal, T is the duration of the captured signal, and t is GPS time as generated by the receiver. The index i is a satellite index and n is a data bit index; $m_i(t)$ is the C/A code modulation normalized to unity magnitude and ω_i is the radian/sec frequency; the signal amplitude and its phase of satellite i and bit n are denoted as $a_{i,n}$ and $\varphi_{i,n}$, respectively. Here, the amplitudes and phases are receiver-generated baseband replica of a noiseless signal for satellite, which are considered to be nuisance parameters involved in minimizing (1) and the minimizer can be given in the equivalent maximization process as follows:

$$J = \sum_{i=1}^{N} \sum_{n=1}^{D} \left| \int_{I_{i,n}} r(t)\, m_i(t)\, a_{i,n} e^{-j\omega_i t} dt \right|^2 \qquad (2)$$

where D is the number of the spanned data bits as received from satellite k and $I_{i,n}$ is the time interval containing the nth of the D data bits from satellite i. Note that the parameters involved in the maximization, which are implicit in the functions $m_i(t)$ and frequencies ω_i, are the receiver position and receiver velocity [10]. The ML parameters estimation of (3) is studied in many literatures [11, 12]. As optimization algorithm, namely SAGE (Space-Alternating Generalized Expectation Maximization) has been investigated for the maximum likelihood position estimation in [13].

Note that open loop tracking strategy is in essence a batch processing strategy and both the pseudorange and Doppler measurements are generated based on maximum likelihood criterion. That is, measurements are generated based on the location of the strongest correlator output and navigation solution is computed from the point in the navigation domain that has the most power. Thus, based on the ML navigation solution, GNSS tracking loop can be designed in a navigation domain.

C.The ML Vector Tracking

By projecting the signal power from all correlators from all satellites into the navigation domain, vector tracking can be implemented based on ML navigation solution estimation.
It has been shown that the direct ML estimation of position and velocity can significantly improve weak-signal tracking capability [13]. Recently, collective detection is proposed as a direct position estimation method, which combines the received power from all GPS satellites in view onto a geographical search space in order to acquire weak signals, and as a by-product, the ML position estimate is also provided [7]. Figure 4 demonstrates the detail architecture of maximum likelihood vector tracking (MLVT), in which the ML navigation solution takes outputs from correlator arrays and the residuals with respect to the previous solution is passed into the navigation filter. The signal parameters such as code phase and Doppler shift are then computed by the updated navigation solution.

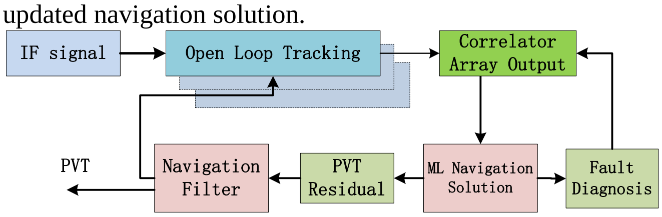

Fig.4 The architecture of MLVT

IV. COLLECTIVE DETECTION AND ITS IMPLEMENTATION

A. Collective Detection

The purpose of acquisition is to determine visible satellites and coarse values of carrier frequency and code phase of the satellite signals. For a successful acquisition, a distinct peak appears in the correlogram bin that corresponds to the true GPS signal's code delay and Doppler frequency. Different from the traditional scalar-based acquisition scheme, collective detection is in essence a vector-based acquisition approach, which combines the received power from multiple satellites onto a geographical search space, and a navigation domain correlogram is created. The grid point that has the highest combined correlation power denotes the ML navigation solution. Thus, the sensitivity will be superior to conventional navigation method and it applies to the weak signal applications such as indoor and urban canyon. Note that the original purpose is to acquire weak signal and the ML position estimation is provided as a by-product [14]. However, for MLVT architecture, it will drive the open loop tracking. Figure 5 shows a basic principle of collective detection.

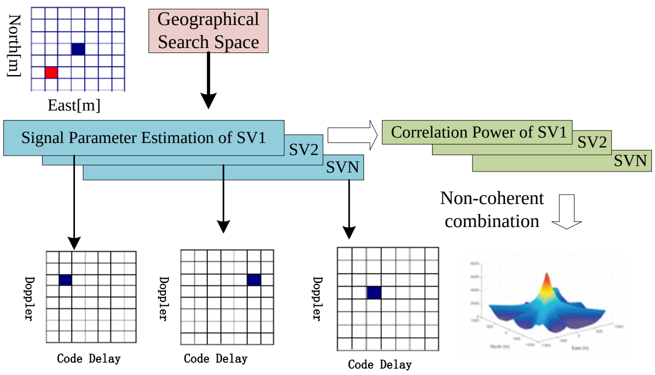

Fig.5 The basic principle of collective detection

In order to formulate a viable position domain search space, a certain position uncertainty should be given, which is typically provided via A-GPS, WiFi or cellular position methods [14]. That is, a priori knowledge, the approximate position of the receiver and the current GPS time are often required for the collective detection technique.

B.The Implementation of Collective Detection

Once the navigation solution is obtained by the receiver, the receiver clock can be corrected to be synchronous with GPS time and the clock-bias could be ignored in a short span. For each candidate grid, the corresponding code phase and the Doppler frequency of each satellite are thus calculated as follows:

$$\left\|\vec{u}\left(t_{rx}^{GPS}\right)-\vec{s}^{\,i}(t_{rx}^{GPS}-\tau_u^i)\right\|+T^i\left[\vec{u}\left(t_{rx}^{GPS}\right)\right]+I^i\left[\vec{u}\left(t_{rx}^{GPS}\right)\right]=c\tau_u^i \quad (3)$$

where $\vec{u}$ denotes the user position coordinate; t_{rx}^{GPS} is the GPS time for the received signal; τ_u^i is the propagation delay from the satellite i to the candidate grid $\vec{u}$; $\vec{s}^{\,i}(t_{rx}^{GPS}-\tau_u^i)$ is the satellite position when the electric signal is sent from the satellite, which can be computed with the known GPS ephemerides; $I^i(\vec{u})$ is ionosphere error and $T^i(\vec{u})$ is the troposphere error; c denotes the speed of light. Equation (3) can be solved iteratively by the dichotomy algorithm, see the reference [15]. However, the propagation delay can also be closely approximated by

$$\tau_u^i \cong \frac{\left\|\vec{s}^{\,i}(t_{rx}^{GPS})\text{-}\vec{u}\left(t_{rx}^{GPS}\right)\right\|}{c+\vec{v}\left(t_{rx}^{GPS}\right)\cdot\vec{e}\left(t_{rx}^{GPS}\right)} \quad (4)$$

where at the received GPS time t_{rx}^{GPS} the vectors $\vec{s}^{\,i}(t_{rx}^{GPS}),\vec{v}\left(t_{rx}^{GPS}\right),\vec{e}\left(t_{rx}^{GPS}\right)$ are respectively the position of satellite i, the velocity of satellite i, and the unit vector pointing from the most recent estimated receiver position to the position of satellite i. These vectors are computed from received satellite ephemeris data. Assuming that the propagation delay τ_u^i is resolved, the signal transmitted time of satellite clock is given by

$$t_{tx}^i = t_{rx}^{GPS} - \tau_u^i + dt^i(t_{rx}^{GPS} - \tau_u^i) \quad (5)$$

where $dt^i(t_{rx}^{GPS} - \tau_u^i)$ is the satellite clock bias at the GPS time $(t_{rx}^{GPS} - \tau_u^i)$. Thus, the received code-phase at GPS time t_{rx}^{GPS} can be computed by the following equation:

$$\hat{D}^i\left(t_{rx}^{GPS}\right)=\text{mod}\left(t_{tx}^i,T_c\right) \quad (6)$$

where $\hat{D}^i\left(t_{rx}^{GPS}\right)$ is the computed code-phase and T_c is the period of the ranging code. Next, the received baseband frequency $\hat{f}^i\left(t_{rx}^{GPS}\right)$ from satellite i is closely approximated by

$$\hat{f}^i\left(t_{rx}^{GPS}\right)=\frac{1}{\lambda}\left[\vec{v}\left(t_{rx}^{GPS}\right)-\vec{v}_k\left(t_{rx}^{GPS}\right)\right]\cdot\vec{u}_k\left(t_{rx}^{GPS}\right) \quad (7)$$

With the estimated code-phase $\hat{D}^i\left(t_{rx}^{GPS}\right)$ and the Doppler frequency $\hat{f}^i\left(t_{rx}^{GPS}\right)$, a local replica signal will be generated. The correlation power is then calculated by the multiplication of the locally generated signal and the sampled signal from the receiver's RF front end. By combining the power from multiple satellites, the total correlation power is given by

$$E\left(k_1,k_2,k_3\right)=\sum_{i=1}^{N}E^i\left(k_1,k_2,k_3\right) \quad (8)$$

where N is the number of visible satellites; k_i is the index of the grid in the different dimension of the geographical search space and $E^i\left(k_1,k_2,k_3\right)$ is the correlation power related to satellite i for the grid $\left(k_1,k_2,k_3\right)$. By traversing all candidate grids, the point that has the highest combined correlation power is assumed as the user position. The grid with a distinct peak in the correlogram bin is giving by

$$\left(\bar{k}_1,\bar{k}_2,\bar{k}_3\right)=\arg\max_{k_1,k_2,k_3}\left[\sum_{i=1}^{N}E^i\left(k_1,k_2,k_3\right)\right] \quad (9)$$

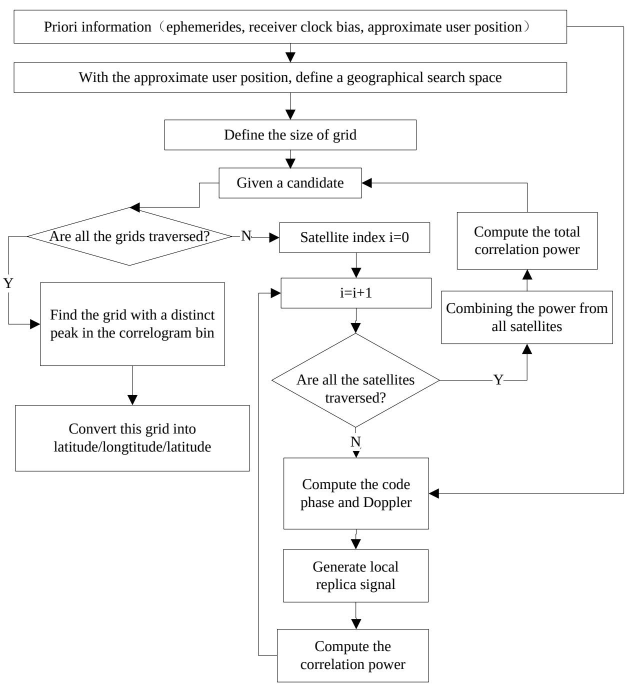

Fig.6 The flow chart of collective detection algorithms

Figure 6 shows the flow chart of the collective detection algorithm, which summarizing the steps given by (3) to (9). Given that a priori knowledge of satellite ephemeris and approximate user location is known, collective detection combines the correlator output of all satellite channels and projects them onto the position-clock space to enhance the overall signal detection probability [16].

C.Performance Assessment

Collective detection is an enhance a powerful approach to enhance the sensitivity of receiver, where the gains acquired can be leveraged on longer coherent/non-coherent integration periods, making it feasible even at about 20dB-Hz C/N0[17]. However, traditional collective detection techniques are computationally intense due to the normal four-dimension scale search space, say North-East-Down-Clock bias [18].

In order to accelerate the traditional collective detection, a practical strategy is to cut down the dimension of the search space. Since the clock-bias dimension is much larger than the other three dimensions, it is assumed to be the major factor that increases the complexity of the collective detection algorithm [19]. Thus, a very fine-time assistance could ease the computational load. For example, if successful position estimation has been done, the receiver clock can be corrected to GPS time and the clock-bias is assumed insignificant in a short period of time. Or else, the estimation of receiver clock bias is too coarse but as least one satellite is strong enough to be acquired individually by the acquisition block. In this case, the reference [19] proposes one method to estimate the clock-bias. The basic principle is that the clock bias can be computed by the difference between the measured code-phase and the geometric code-phase. The former can be extracted by the strong satellite's correlogram and the latter is calculated by the computed geometric range.

Note that both the position accuracy and computational load are also determined by the step sizes or the density of grid partition. That is, the computational load decreases as the step size decreases, however, the accuracy of position also decreases. Hence, a balance should be achieved for the step size between the computing time and accuracy.

V. QUASI-OPEN LOOP ARCHITECTURE

A. Open Loop Tracking With Collect Detection Strategy

In MLVT the navigation solution actually takes outputs from correlator arrays as "measurements" to directly detect a navigation solution with a maximum likelihood criterion. Based on the collective detection technique, the maximum likelihood navigation solution and the corresponding code phase and Doppler of each satellite are all provided. Although the direct navigation solution is coarse, the accuracy of navigation solution can be improved by a navigation filter and the output of navigation filter could be used to update the priori information for the next estimation. Both the code phase and Doppler are used to generate the local replica signal. That is, the local carrier replica and the local code replica, by comparing with the incoming signal, the discriminator compute the signal estimation error, which enters the following open loop tracking. Since the discriminator output is corrupted by thermal noise, the filter is also required to provide a degree of noise rejection, see the "Integrate and Dump Filter" unit in Figure 7. Next, the filtered error enters the fine estimator to achieve an exact tracking. As depicted in Figure 7, in order to estimate the time delay and the carrier frequency from the incoming signal, the open loop schemes usually operate on batches of the incoming signal. Thus, this approach allows using longer integration time, and both code phase and Doppler measurements are generated based on the location of the strongest correlator output, indicating that the performance of the measurements asymptotically approaches the Cramer-Rao lower bound. The loop stability problem can be well circumvented by the proposed open loop tracking strategy. Note that, there is no feedback loop in the open loop control, thus the key issue of the whole open loop control is "How to obtain high precision tracking results from the input signal?"

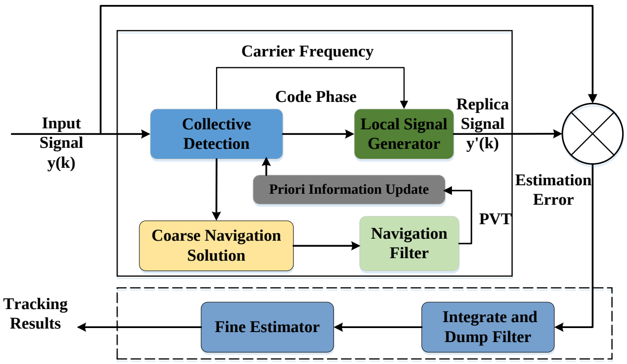

Fig.7 Open loop architecture with collect detection strategy

B.The Quasi-Open Loop Vector Tracking Architecture

Although the precision of open loop tracking results can be improved by some mathematical approaches such as the weighted multiple regression estimation and the nonlinear least squares, the actual tracking precision is significantly worse than the vector tracking with closed loop tracking strategy. Thus, in this paper we propose a novel tracking scheme, based on a novel quasi-open loop architecture, which relieves the stress on the vector tracking in terms of stability in harsh environment and also keeps a high precision tracking under normal circumstances.

Figure 8 demonstrates the quasi-open loop vector tracking architecture, which combines the good properties of both open loop and closed loop architectures. The combined approach of the block processing and centralized vector-based tracking can be utilized for robust indoor/outdoor navigation. In other words, when the receiver is under open-sky conditions, the closed loop vector tracking is used; when the signal power drops, signal fading level increases, or the Kalman filter tracking loops have difficulty to keep lock, the open loop tracking is enabled. A context-aware approach can be used to rapid recognize the signal environment and optimize the processing load of the receiver and the measurement weighting [20].

As is depicted in Figure 8, for the open loop tracking mode, the incoming IF data will first enter the collective detection algorithms, in which the ML position estimation is given, by-product, the code phase and carrier frequency are also provided to the local code NCO and carrier NCO. The local replica signal can thus be generated for each tracking channel.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 12, December - 2017

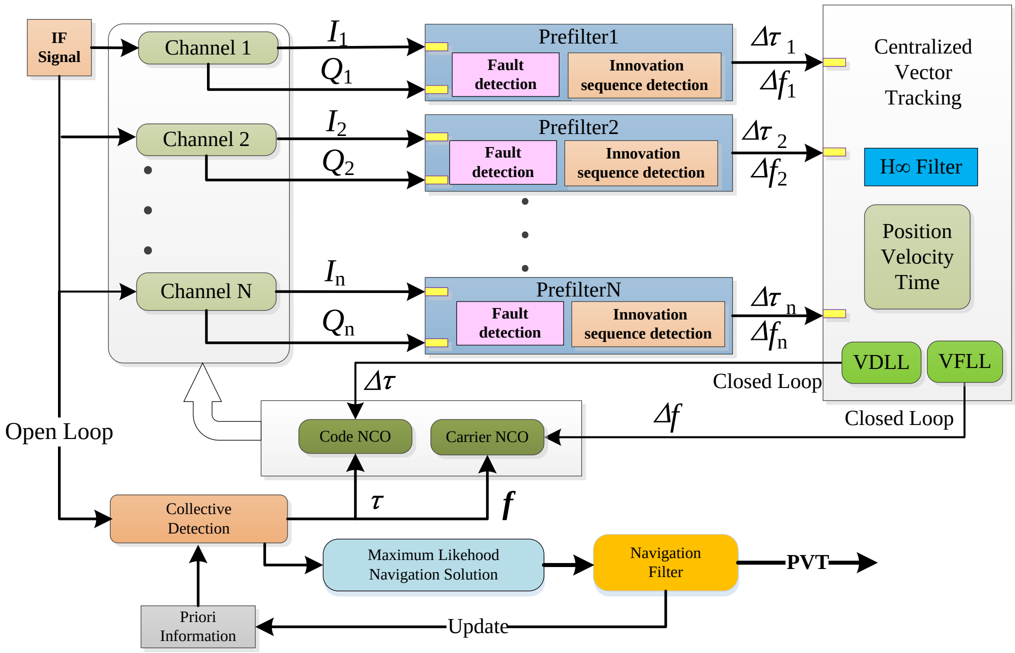

Fig.8 The quasi-open loop vector tracking architecture

Next, by performing the multiplication between the local replica and the incoming signal for each channel, both the in-phase (I) and quadrature (Q) correlation outputs can be calculated.

Different from the open loop tracking, the local code NCO and carrier NCO are controlled by the increments of code and carrier frequency respectively, which are the outputs of VDLL and VFLL in the centralized vector tracking filter. That is, the feedbacks of navigation filter control the code NCO and carrier NCO to generate the local replica signal.

In the architecture above, the navigation and positioning function is realized by using a main filter and multiple parallel tracking prefilters. In the fault detection section of the prefilter, the residual chi square test is utilized to detect the fast abrupt fault, and the slow variation fault of the system is detected by the following innovation sequence detection. The combinations of both detection methods greatly reduce the influence of channel faults on the data fusion and maintain a high precision tracking in the case of failures. Each channel is processed with a prefilter, and all the prefilters works in parallel prior to entering the main filter.

Note that, instead of a Kalman filter, the main filter is designed based on H infinity robust filtering, which can improve the robustness and guarantee the accuracy and real time. Thus, the proposed architecture is an inherently stable architecture, and this architecture can work with extended integration times to improve the sensitivity. Also, to a certain extent, the dynamic can be compensated by VFLL.

C. GNSS/INS Tightly Coupled Vector Tracking Architecture

However, for high dynamic applications, the proposed architecture should be further improved. The compensation of the user dynamics is necessary. For example, the tracking loops can be assisted by a tightly coupled inertial navigation system (INS). Considering the optimal information fusion, the proposed quasi-open loop vector tracking architecture is extended as follows.

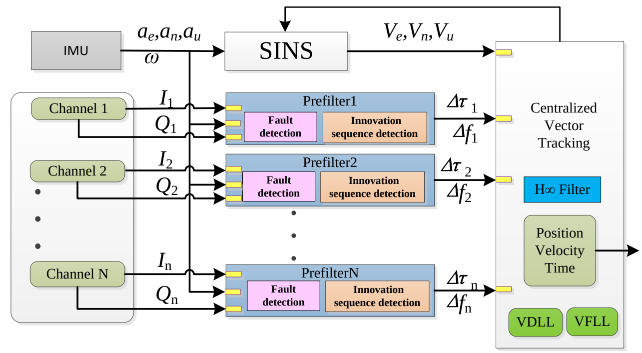

Fig.9 Vector tracking architecture with tightly integrated system (The part that is not displayed is the same as Figure 8)

As is shown in Figure 9, the raw measurements of IMU (inertial measurement unit) enter all the prefilters and SINS and the outputs of all prefilters and SINS are input into the centralized vector tracking filter. The final navigation solution is used to assist the receiver tracking loop and make the correction on the SINS. The acceleration information provided by the inertial navigation can effectively improve the loop's equivalent bandwidth and the receiver's anti-interference ability and reduce the error caused by dynamic stress. Thus, the proposed architecture has high accuracy, high stability and strong fault tolerance and robustness.

VI. RESULTS AND DISCUSSION

A. The Position Domain Projected Correlogram

In a typical weak signal environment like deep urban canyon, individual acquisition correlograms cannot be used to decide on the code-phase and Doppler-frequency, since there is no a distinct peak, see Figure 10.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 12, December - 2017

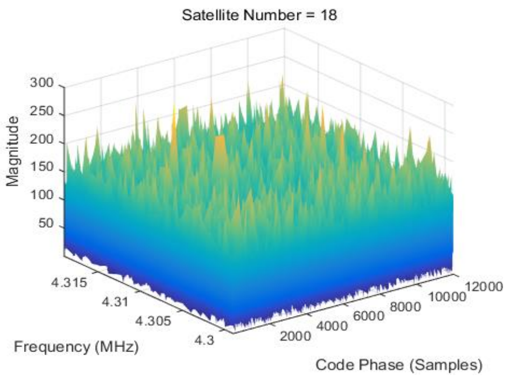

Fig.10 The correlogram for a weak GPS signal acqusitiuon in a deep urban canyon (IF Frequency:4.309MHz;Sampling Frequency:12MHz)

However, in collective detection process, the discrete correlation values, selected by calculating its code-phase and Doppler based on the hypothesized position in the position domain, are non-coherently combined. By repeating all position domain search cell, the correlation surface is named the position domain projected correlogram, see Figure 11. Note that even if all signals are too weak to be acquired and tracked by the traditional approach, a quick and coarse position solution can be directly estimated by combining the received signal power from each satellite.

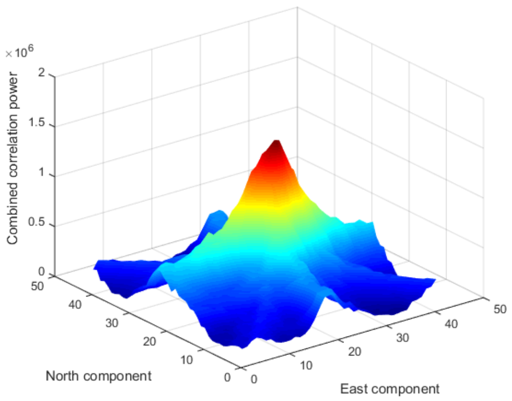

Fig.11 Position domain projected correlogram (The step sizes of both the north component and east component are 50m, using seven satellites and the priori height; the local receiver clock is synchronized with GPS time)

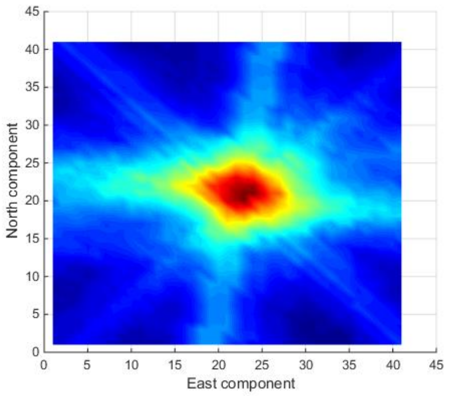

Fig.12 Top view of the position domain projected correlogram in Fig.11

Figure 12 demonstrates the top view of the position domain projected correlogram. The black center area indicates the sharpness of the peak.

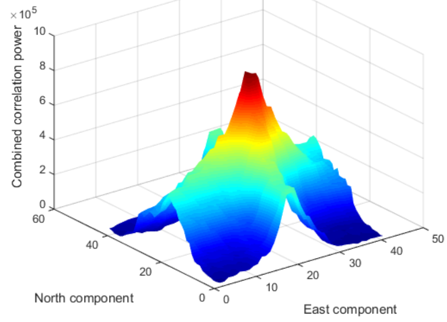

Fig.13 Position domain projected correlogram (The step sizes of both the north component and east component are 50m, using three satellites and the priori height; the local receiver clock is synchronized with GPS time)

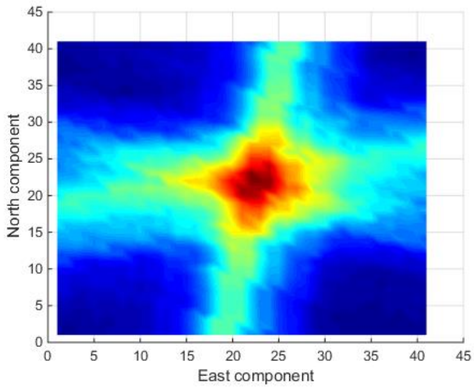

Fig.14 Top view of the position domain projected correlogram in Fig.12

In Figure 11 and Figure 12, the correlogram of seven satellites are combined. For comparison purposes, Figure 13 and Figure 14 demonstrate the combined correlogram with only three satellites, indicating that the position estimation can be achieved with poor visible satellites. It is also shown that the peak in Figure 11 is sharper than that in Figure 13 and the black center area in Figure 14 is larger than that in Figure 12, representing that the accuracy decreases as the number of satellites decreases.

B. Assessment of Proposed GNSS/INS Tightly Coupled Vector Tracking Architecture

In order to evaluate the proposed GNSS/INS tightly coupled vector tracking architecture, the simulation experiment has been performed based on the following scheme:

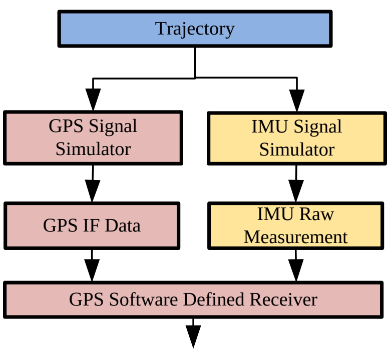

Fig.15 The scheme of simulation experiment

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 12, December - 2017

The simulated trajectory is provided in Table 1 and initial position is (5ºN, 5 ºE, 5m) and the initial attitude is (0º,0º,0º).The moving direction of vehicle is north. The simulation parameters of IMU is given in Table 2. The initial alignment error of SINS is not taken into account. Both the GPS IF data and the raw measurements of IMU are entered into the GPS Software-Defined Receiver, in which the proposed vector tracking architecture is implemented, see Figure 9. The important parameters for the signal processing are

- Sampling frequency: 12MHz
- Intermediate frequency: 3.563 MHz, and
- Sampling bits: One bit
- Integration time: 10ms
- Bandwidth of code loop:1Hz
- Bandwidth of carrier loop:10Hz

TABLE I. TRAJECTORY SIMULATION

Time(s)	Simulation Parameters		
	Speed(m/s)	*Acceleration(m/s^2)*	*Jerk(m/s^3)*
0	0	0	0
0-35	0	0	0
35-45	—	—	10
45-55	—	100	0
55-70	—	—	-20
70-77	—	-200	0
77-92	—	—	20
92-102	—	100	0
102-112	—	—	-10
112-125	—	0	0

For comparison purposes, the noise is assumed as colored in the simulation. The extended Kalman filter and H infinity robust filtering are both implemented in the centralized vector tracking filter. The error curve of position and velocity in X and Z directions are provided respectively, see Figure 16, 17, 18 and 19. The error curves of position and velocity in Y direction are similar with those in X direction.

TABLE II. SIMULATION PARAMETER OF IMU

Parameter	**Gyro**		**Accelerometer**	
	Constant Drift (°/h)	***Random Drift(°/h)***	***Zero Offset (m/s^2)***	***Random Drift(m/s^2)***
Accuracy	0.1	0.1	1e-4	1e-4

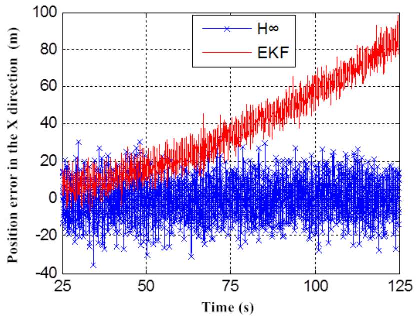

Fig.16 The position error in the X direction

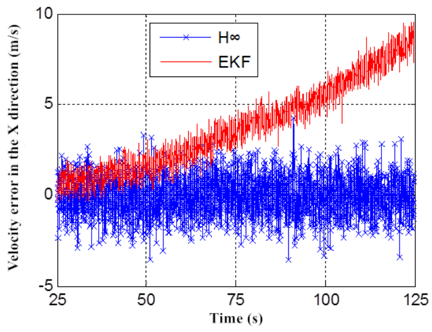

Fig.17 The velocity error in the X direction

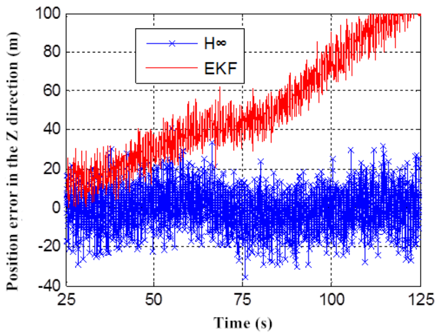

Fig.18 The position error in the Z direction

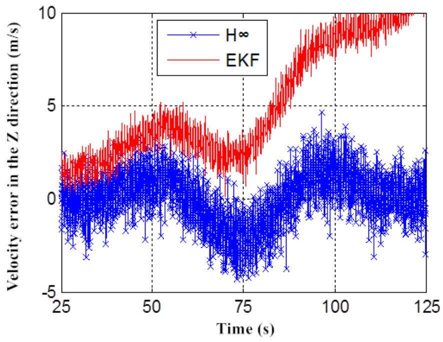

Fig.19 The velocity error in the Z direction

As is shown in the figures above, in the presence of colored noise, the position and velocity measuring errors of EKF filter divergence with time. However, for the H infinity filter, both the position and velocity measuring errors slightly worse compared to the EKF filtering. Hence, it can be concluded that H infinity filtering has very strong robustness and even if the input signal contains a constant and random drift and colored noise, the filter could eventually converge.

VII. CONCLUSIONS

In this contribution, a novel quasi-open loop architecture has been proposed for robust tracking in harsh environments such as weak signal and high dynamic environments. The proposed architecture works with the combination of open loop tracking scheme and the closed loop tracking scheme. The open loop tracking is achieved based on ML navigation solution, which is provided by collective detection technique. The closed loop tracking is performed with VDLL plus VFLL architecture and both fault detection and H infinity filter are also utilized. The proposed architecture could provide a feasible way to GNSS/INS tightly coupled vector tracking. It indicates that the stability, robustness, dynamics and sensitivity can be well taken into account at the same time.

ACKNOWLEDGMENTS

This work is supported by the National Natural Science Foundation of China (Grant No. 61401468)

REFERENCES

[1] B. Parkinson and J. Spilker, Eds., Global Positioning System:Theory and Applications, vol. 1, American Institute of Aeronautics and Astronautics,Washington, DC, USA, 1996.

[2] E. Kaplan and C. Hegarty, Eds., Understanding GPS Principles and Applications, Artech House, Norwood, Mass, USA, 2006.

[3] Weill L., "A High Performance Code and Carrier Tracking Architecture for Ground-Based Mobile GNSS Receivers", Proceedings of International Technical Meeting of the Satellite Division of the Institute of Navigation, 2010, pp. 3054-3068.

[4] Bradley B.K., Axelrad P., Donna J., and Mohiuddin S., "Performance Analysis of Collective Detection of Weak GPS Signals," Proceedings of the 23rd International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2010), Portland, OR, September 21-24, 2010, pp. 3041-3053.

[5] Tsui J., Fundamentals of Global Positioning System Receivers: A Software Approach. John Wiley & Sons, New York, NY, 2000.

[6] Petovello, M.G.,Sun D., Lachapelle G., " Performance Analysis of an Ultra-Tightly Integrated GPS and Reduced IMU System", Proceedings of International Technical Meeting of the Satellite Division of the Institute of Navigation, 2007.

[7] Lashley, Matthew, and David Bevly, "GNSS Solutions: What is a maximum likelihood vector tracking receiver?" Inside GNSS, July/August 2013.

[8] J. Riba, J. Tom, and M. Lagunas, "Instantaneous openloop frequency estimation methods for navigation receivers," in Proceedings of the 2nd European Symposium on Global Navigation Satellite Systems (GNSS'98), Toulouse, France, 1998.

[9] Muhammad Tahir, Letizia Lo Presti, and Maurizio Fantino, "A Novel Quasi-Open Loop Architecture for GNSS Carrier Recovery Systems," International Journal of Navigation and Observation, Volume 2012, Article ID 324858, 12 pages.

[10] Weil, L. R., "A High Performance Code and Carrier Tracking Architecture for Ground-Based Mobile GNSS Receivers," in Proceedings of the 23nd International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2010), Portland, Oregon USA, pp. 3054-3068, 2010.

[11] Closas P., Fernandez-Prades C. and Fernandez-Rubio J., "Maximum Likelihood Estimation of Position in GNSS", IEEE Signal Processing Letters, 2007, 14(5): 359 - 362.

[12] Closas P., Fernandez-Prades C., Fernandez-Rubio J. et al., "On the Maximum Likelihood Estimation of Position," in Proceedings of the ION GNSS 2005, Long Beach, CA, September 2005.

[13] Closas P., Fernandez-Prades C. and Fernandez-Rubio J., "ML Esimation of Position in a GNSS Receiver using the SAGE Algorithm", IEEE International Conference on Acoustics, 2007.

[14] Axelrad P., Bradley B. K., Donna J., Mitchell M., Mohiuddin S. "Collective Detection and Direct Positioning Using Multiple GNSS Satellites", Navigation: Journal of The Institute of Navigation, Vol. 58, No. 4, Winter 2011, pp. 305-321.

[15] Wantong Chen. "New Method for GPS Direct Position Estimation Based on Collective Detection Approach", International Journal of Engineering Research & Technology, 2017, 6(12): 132-136.

[16] Joon Wayn Cheong. "Towards Mluti-Constellation Collective Detection for Weak Signals: A Comparative Experimental Analysis", Proceedings of the ION GNSS, 2011, pp. 3709-3719.

[17] Zhe He, V. Renaudin, M. G. Petovello and G. Lachapelle, "Use of High Sensitivity GNSS Receiver Doppler Measurements for Indoor Pedestrian Dead Reckoning", Sensors 2013, 13, pp. 4303-4326.

[18] Maherizo Andrianarison, Mohamed Sahmoudi, René Landry, "Innovative techniques for Collective Detection of multiple GNSS signals in challenging environments", Indoor Positioning and Indoor Navigation (IPIN) 2016 International Conference on, pp. 1-8, 2016, ISSN 2471-917X.

[19] Lakshay Narula, Keshava P.Singh,Mark G.Petovello. "Accelerated collective detection technique for weak GNSS signal environment", 2014 Ubiquitous Positioning Indoor Navigation and Location Based Service (UPINLBS), 20-21 Nov. 2014, pp.81-89.

[20] T Lin, C O'Driscoll, G Lachapelle. "Development of a Context-Aware Vector-Based High-Sensitivity GNSS Software Receiver", Proceedings of the International Technical Meeting of the Institute of Navigation, 2011, pp.1043-1055.