Indoor and Outdoor Fusion Positioning Technology Based on BeiDou Satellite Navigation

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Abstract. In order to solve the inaccuracy and discontinuity of BeiDou differential indoor and outdoor navigation and positioning, this article highlights an indoor and outdoor fusion positioning method based on BeiDou differential and WIFI. This positioning method combines the micro-inertial navigation positioning technology with a single positioning method such as Bluetooth, WIFI fingerprint, ZigBee, ultra-wideband UWB, etc., to correct the BeiDou pseudo range equation to reduce the spatial pseudo range error. And it can integrate BeiDou differential pseudo range equation and linear filtering algorithm to achieve precise positioning of navigation. The research results show that the method realizes the positioning of the indoor and outdoor interactive area by fusing the satellite pseudo-range equation and the base station pseudo-range equation. And it realizes the seamless integration of indoor and outdoor precise positioning, which improves the positioning accuracy and reliability.

Key words: BeiDou satellite navigation; pseudo range correction; WIFI; fusion positioning.

1. Introduction

In recent years, with the rapid development of Chinese BeiDou satellite navigation (BD) and positioning technology industry, the in-depth study of the GNSS (Global Navigation Satellite System) high-precision positioning theory and method has provided an effective and reliable method for intelligent individual positioning. Ways to achieve it. GNSS has the advantages of globalization, all-weather navigation capability, long-term error stability, and low receiver cost. However, satellite signals are susceptible to factors such as geographic environment interference, occlusion, etc., resulting in the inability to capture satellite signals and the loss of positioning functions, and the positioning requirements in indoor environments cannot be achieved. And GNSS can usually only output the position and speed information of the carrier, and the output bandwidth is low [1]. In order to ensure the continuity of positioning services and make up for problems such as low positioning accuracy of a single system and positioning blind spots, seamless indoor and outdoor positioning has become one of the problems that need to be studied and solved urgently. At present, BD and WIFI modules have been widely used in mobile phone terminals, providing the possibility for the integration of the two. Therefore, this paper proposes a seamless indoor and outdoor positioning method based on the integration of BD and WIFI. BD positioning adopts multi-base station pseudo-range differential positioning algorithm. WIFI positioning uses a ranging model positioning method based on received signal strength indicator (RSSI).

2. Analysis and establishment of BeiDou satellite navigation signal model

2.1 Indoor and outdoor interactive areas

By fusing different positioning systems that are suitable for outdoor and indoor environments, the indoor and outdoor interactive areas (positioning blind areas of the two positioning systems) are positioned [2].

The inside of the solid line rectangle represents the indoor area, the area outside the solid line rectangle represents the outdoor area, and the ring-shaped part between the two dotted rectangles represents the indoor and outdoor interactive area. In this area, the outdoor satellite positioning system cannot be used for positioning due to the insufficient number of received satellite signals [3]. At the same time, the area is at the edge of the coverage of the indoor positioning system, and the positioning effect is not good or even positioning cannot be completed.

In an outdoor environment, this solution designs a fusion positioning mechanism: when the BD signal quality is good, it uses GNSS and inertial navigation MINS positioning results, and obtains the final positioning information by fusing the Kalman filter. When the BD signal quality is poor, switch to the MINS positioning result. Respectively realized the flexible switching of outdoor BD positioning and micro-inertial navigation positioning.

The GNSS data validity screening uses the following three indicators: (1) Judging the validity of the GNSS positioning results of each frame: that is, judging whether the latest GNSS positioning results are calculated from the newly received signals, and only valid data frames are selected to evaluate the positioning quality. (2) The number of effective satellites: that is, the pseudo range measurement value used to calculate the position calculated by the current data frame comes from several satellites. The more satellites are used, the more accurate the calculated position is. (3) Satellite horizontal geometric distribution factor: characterizes the distribution of BeiDou satellites on the horizontal plane. The smaller the value, the higher the current accuracy. In an indoor environment, this solution uses ultra-wideband ranging information and inertial positioning information, and machine vision-assisted positioning information for indoor fusion positioning. Before using the UWB ranging information, the UWB base station needs to be arranged. The position of the UWB base station proposed in the plan is given by the inertial navigation positioning. Because it is used from outdoor scenes to indoor scenes in actual use, Therefore, it is believed that the positioning information of the inertial navigation at the initial stage is credible and can be used as the coordinates of the ultra-wideband position.

When a person moves indoors, select a specific location on the walked route to deploy UWB base stations, usually stair openings, long corridors, and other locations that may have multiple paths. The UWB base station deployment position is determined by the current position information given by the personnel inertial positioning [4]. The deployment number of UWB base stations increases or decreases according to the actual environment. When the UWB base station is deployed, the individual handheld terminal will automatically generate the location information of the UWB base station deployed in the current indoor environment. When the personnel enter the UWB ranging range, they can merge with the inertial navigation positioning information. If there is already UWB base station deployment information in the current indoor area, you only need to search and collect the indoor UWB base station ranging and positioning information, and based on the measurement The validity of the range data is fused with the micro-inertial positioning information. If there is no effective UWB range finding information in the current area where the personnel are located, the inertial navigation will give the personnel positioning information according to the inertial navigation solution process.

2.2 Differential BD-WIFI fusion positioning algorithm

Signal quality has a greater impact on positioning performance. Fusion positioning needs to select the combination of beacons participating in positioning based on signal strength and signal-to-noise ratio. BD and WIFI are heterogeneous networks, so beacon optimization first needs to determine the signal strength and signal strength of the two. The noise ratio is normalized [5]. The linear filtering algorithm closely correlates the uncertainty of the Q matrix and the R matrix with the residual $r_k^{'} = Z_k - H_k \widehat{X}_{k/k-1}$, the estimated mean square error matrix P_k and the one-step prediction mean square error matrix $P_{k/k-1}$. The linear filtering algorithm with forgetting factor makes the current information give the largest weight to the adaptive estimation Q matrix and (or) R matrix. The linear discretization system equation and measurement equation used are:

$$\begin{cases} X_k = \phi_{k,k\text{-}1} X_{k\text{-}1} + \xi_{k\text{-}1} \\ Z_k = H_k X_k + \eta_k \end{cases} \tag{1}$$

Where X_k is the estimated state at time t_k (n×1), $\phi_{k,k\text{-}1}$ is the state transition matrix at time t_{k-1} to t_k (n×n), $\xi_{k\text{-}1}$ is the system excitation noise sequence (n×1), and η_k is the measurement noise sequence (m× 1) Suppose it is an uncorrelated sequence, satisfying: $\begin{cases} E[\xi_{k\text{-}1}] = q_{k\text{-}1}, E[\eta_k] = r_k \\ \mathrm{cov}[\xi_k, \xi_j] = \delta_{kj} Q_k, \mathrm{cov}[\eta_k, \eta_j] = \delta_{kj} R_k \end{cases}$. The iterative steps of the linear filtering algorithm are:

$$P_{k/k-1} = \phi_{k,k-1} P_{k-1} \phi_{k,k-1}^T + \hat{Q}_{k-1} \tag{2}$$

$$\widehat{X}_{k/k-1} = \phi_{k,k-1} \widehat{X}_{k-1} + \widehat{q}_{k-1} \tag{3}$$

$$\widehat{r}_k = (1-d_k)\widehat{r}_{k-1} + d_k (Z_k - H_k \widehat{X}_{k/k-1}) \tag{4}$$

$$v_k = Z_k - H_k \widehat{X}_{k/k-1} - \widehat{r}_k \tag{5}$$

$$\widehat{R}_k = (1-d_k)\widehat{R}_{k-1} + d_k (v_k v_k^T - H_k P_{k/k-1} H_k^T) \tag{6}$$

$$K_k = P_{k/k-1} H_k^T [H_k P_{k/k-1} H_k^T + \widehat{R}_{k-1}]^{-1} \tag{7}$$

$$P_k = (I - K_k H_k) P_{k/k\text{-}1} (I - K_k H_k)^T + K_k \widehat{R}_{k-1} K_k^T \tag{8}$$

$$\widehat{X}_k = \widehat{X}_{k/k-1} + K_k v_k \tag{9}$$

$$\widehat{q}_k = (1-d_k)\widehat{q}_{k-1} + d_k (\widehat{X}_k - \phi_{k,k-1} \widehat{X}_{k-1}) \tag{10}$$

$$\widehat{Q}_k = (1-d_k)\widehat{Q}_{k-1} + d_k (K_k v_k v_k^T K_k^T + P_k - \phi_{k,k-1} P_{k-1} \phi_{k,k-1}^T) \tag{11}$$

$$d_k = (1-b)/(1-b^{k+1}) \tag{12}$$

3. Experimental simulation analysis

Table 1. List of inertial navigation system error variables and initial values

Serial number	Error variable meaning	Initial error
1	X axis speed error	0.1m/s
2	Y axis speed error	0.1m/s
3	Latitude error	1.0"
4	Longitude error	1.0"
5	Deflection angle of platform around X axis	30"
6	Deflection angle of platform around Y axis	30"
7	Deflection angle of platform around Z axis	50"
8	Wandering angle error	1200"
9	X-axis gyro drift	0.05°/h
10	Y-axis gyro drift	-0.05°/h
11	Z-axis gyro drift	-0.10°/h
12	X-axis accelerometer zero offset	4×10^{-5}g
13	Y-axis accelerometer zero bias	4×10^{-5}g
14	X-axis accelerometer misaligned angle around Z-axis	10
15	Y-axis accelerometer misaligned angle around Z-axis	12
16	X-axis gyro scale factor error	-0.001
17	Y-axis gyro scale factor error	0.001
18	Z-axis gyro scale factor error	-0.001
19	X-axis accelerometer scale factor error	0.001
20	Y-axis accelerometer scale factor error	0.001
21	XX axis gyroscope mass imbalance error	-1.7º/h/g
22	ZX axis gyro quadrature error	1.7º/h/g
23	YY axis gyroscope mass unbalance error	-1.2º/h/g
24	ZY axis gyro quadrature error	1.2º/h/g

In order to more comprehensively simulate the interference factors in the practical application of inertial/GPS integrated navigation, three types of representative data disturbance situations are specially designed: 1) The amount of error is abnormal. There are error sources other than the error equation, including general or larger values. According to Table 1, the initial values of 24 errors are added. 2) The measurement data is interrupted, that is, the combination is disconnected for a period of time. Break the combination twice at 301s-899s and 5301s-5899s. 3) GPS navigation data fluctuates, add 3 kinds of errors to GPS longitude and latitude: I) Jump point, 1001s-1003s, 300". II) Step, 1501s-1800s, 60". III) Slope, 2001s-2600s, slope 0.067"/s.

For time-varying systems, it is more difficult to determine whether the Kalman filter is stable. For the actual situation of the inertial navigation system, the relatively wide filter stability condition is: if the system is completely random and detectable, and P0>0, the Kalman filter is stable [6]. The difficulty of this condition is to determine whether it is completely random and detectable. This is only related to, we use the minimum value of the cost function, or make the linear norm of the closed-loop transfer function that interfere with the estimation error of the system to be less than γ, etc., to provide guarantee for the stability of the filtering as much as possible. If only from the perspective of normal calculation, the condition of Kalman filter formula (7) is obviously more relaxed, that is, if the inertial navigation system error equation is selected, and only P0≥0 and symmetry, Rk>0 and symmetry and Qk≥ 0 and symmetric, a continuous error estimate can be obtained.

Although it may be due to the error model, and the inaccuracy of Rk and Qk, the error estimation may be biased. If the Kalman filter uses information filtering equations including Pk-1 and Pk/k-1-1 in order to avoid difficulties in the calculation of P1/0 and K1 by choosing a huge P0 matrix, the requirements must always be satisfied Pk>0 and Pk/k-1>0, in this case, the constraints of Kalman filter are increased. For linear filtering, a conservative and safe approach is to reduce θ, for example, θ=0.015 to reduce the chance of singularity in Pk inversion. One of the starting points for the design of linear filtering is that Rk and Qk can be completely unknown. The algorithm can automatically adjust Rk and Qk. The next section will verify this adjustment ability.

4. Conclusion

The article uses the multi-attribute cost function to realize the selection of the optimal beacon combination. The pseudo range difference of multiple reference stations based on inverse distance weighting is used for pseudo range correction, and Taylor iteration is used to estimate the optimal positioning of the fusion pseudo range equation of BD and WIFI to realize terminal fusion positioning. The experimental results show that the method realizes the indoor and outdoor fusion positioning of WIFI and BD, solves the positioning coverage defect of a single system, and effectively improves the positioning accuracy and robustness.

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References

[1] Yan Li. Research on the Theory and Algorithm of BDS/GPS Fusion Precision Positioning. Journal of Surveying and Mapping, 49(6) (2020) 1-5.

[2] Wang Ershen, Song Yuanshang, Xu Song, et al. Research on Navigation and Surveillance Technology of Low Altitude Airspace Aircraft Based on "BeiDou". Journal of Nanjing University of Aeronautics and Astronautics, 51(5) (2019) 6-12.

[3] Zhao Juan, Bai Chun, Hu Yahui, et al. Shipborne UAV inertial navigation and positioning system based on BeiDou satellites. Ship Science and Technology, 42(8) (2020) 143-145.

[4] Peng Xiaoqiang, Yu Xuexiang, Chen Weiwei, et al. Research on Kalman Filtering Algorithm for Vehicle-mounted Pseudorange Single Point Positioning. Journal of Anhui University of Science and Technology: Natural Science Edition, 39(6) (2019) 6-12.

[5] Guan Weiguo, Jiao Meng, Sun Fuming, et al. Indoor and outdoor fusion positioning method based on BeiDou pseudo range difference and WIFI. Sensors and Microsystems, 38(5) (2019) 13-16.

[6] Li Shigang, Chang Peng. Research on Underwater BeiDou Accurate Navigation and Positioning System Technology. Command Control and Simulation, 42(1) (2020) 5-10.