The research of filter tracking algorithm based on novel hybrid navigation positioning system

Anhong Tian*, Chengbiao Fu

Department of Computer Science and Engineering, Qujing Normal College, Qujing 655000, China

Received 1 October 2014, www.cmnt.lv

Abstract

In order to overcome the deficiency of location failure caused by lack of GPS satellites in dense urban environment with skyscraper, in view of the advantages of terrestrial digital television signal. This paper proposes a novel hybrid positioning system combining GPS and DTMB, and the model of hybrid positioning system has also been presented. Under different number of particles, we simulate the tracking effect base on particle filter algorithm, theoretical analysis and simulation results show that the filtering trajectory is essentially consistent with true trajectory, good dynamic tracking effect is meet for the precision demand of urban environment, in addition, the more particle number, the better positioning accuracy, the smaller mean error and standard deviation. Thus in GPS blind areas, the fusion of multiple source signals has been utilized to ensure positioning accuracy, and the feasibility and superiority of combining GPS and DTMB has been verified in urban areas, the proposed method can be adopted as a supplement for urban environments in the case of GPS failure, which can improve the positioning performance of navigation system.

Keywords: combined positioning model, particle filter algorithm, nonlinear equation, global positioning system, digital television terrestrial multimedia broadcasting

1 Introduction

With the aid of the many Global Positioning System (GPS) satellites surrounding the earth, GPS covers a wide area, and provides high precision positioning for the mobile user in outdoor environment [1], which has been applied in many fields. However, the GPS signal on the ground is too weak to be received in an indoor environment, and the GPS signal will be blocked by skyscrapers in urban environment, so GPS fails to achieve accurate positioning in urban environment and indoor environment.

To solve the problem of accurate navigation in urban environment, many studies have been carried out integrated navigation positioning technology, the data fusion technology mainly includes ground radio signals and GPS signals, such as cellular network, UWB, Wi-Fi and so on. But many of these positioning systems have limitation such as auxiliary equipment or prior data processing, however, to serve a seamless positioning in urban environments, the terrestrial digital television (DTV) broadcasting signal is adopted [2]. DTV signal has the advantages of high received power and positioning accuracy, low cost and operating frequency [3], wide signal bandwidth. In addition, compared with GPS signal, DTV signal intensity is more than 30 dB, which can penetrate buildings easily, at present the new generation of digital terrestrial broadcasting in China - Digital Television Terrestrial Multimedia Broadcasting(DTMB) has inspired wide research interest [4], which has covered the majority of cities. Thus this paper presents a novel hybrid positioning system, which is combing GPS signal and DTMB signal, in dense urban and indoor environments where GPS performs badly or even fails to work [4-6].

Chinese DTMB standard has been formally formulated and promulgated on August 18, 2006, before the standard promulgated, there is a phenomenon of China's digital TV standard chaos, DTMB standard completely solves the problem, which has brought opportunity for carrying out navigation positioning technology research and application based on digital television terrestrial broadcasting signals in China. However, the work of research is in its infancy, in view of the advantage of DTMB signal positioning, to date, several investigations of DTMB positioning technology can be found in the literature, but there is little studies about hybrid system combing DTMB and other navigation positioning technology, the studies mainly concentrate in the brief description of integrated navigation positioning ideas, and the realization of localization filter algorithm had not been included in the studies. Thus this paper deeply studies the hybrid positioning system combing GPS and DTMB, and presents the model of integrated navigation system, which is nonlinear equation, due to the linearization error of Extended Kalman Filter (EKF) algorithm, and Particle Filter (PF) algorithm can be applied to any dynamic state space model, this article studies the dynamic target tracking effect of PF in integrated navigation system. There is a development direction of multiple signal fusion in urban navigation and positioning technology. This paper

***Corresponding author's** e-mail: tiananhongqjnc@163.com

put forwards the hybrid positioning system combing GPS and DTMB, through experimental simulation, the feasibility of this new hybrid positioning system have been verified in urban environment.

2 Hybrid positioning system combining GPS and DTMB

In order to make up for the defect that GPS fails to locate the accurate location information in urban environment [7-10], a novel integrated navigation system combing GPS and DTMB is proposed. DTMB transmitter can be seen as pseudolite, which is a supplement for GPS satellite. This article focuses on the nonlinear filtering algorithm of integrated system, and the model of hybrid positioning system can be shown in Figure 1.

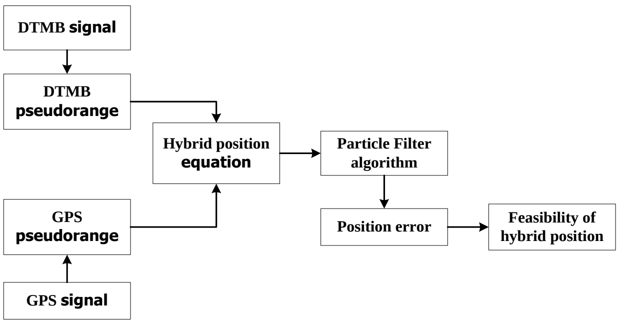

FIGURE 1 The model of hybrid positioning system combining GPS and DTMB

In the hybrid positioning system combining GPS and DTMB, a pseudo-range position method is adopted, since the system clock between GPS and DTMB is not synchronized with each other, which means that there is need for processing the time offset before positioning calculation, so the hybrid positioning equation can be formulated as:

$$\begin{cases} \rho_i = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} + b_u \\ \rho_D = \sqrt{(x_D - x_u)^2 + (y_D - y_u)^2 + (z_D - z_u)^2} + b_u + b_D \end{cases}, \quad (1)$$

where ρ_i is the pseudo-orange measurement between GPS satellite and object receiver, ρ_D is the pseudo-orange measurement between DTMB transmitter and object receiver, (x_i, y_i, z_i) is the coordinate of GPS satellite, (x_D, y_D, z_D) is the coordinate of DTMB transmitter, (x_u, y_u, z_u) is the coordinate of object receiver, b_u is the time offset between DTMB transmitter and object receiver, b_D is the time offset between DTMB transmitter and GPS satellite.

3 State equation and observation equation

From Equation (1) the integrated navigation positioning system equation is nonlinear equation, the EKF algorithm can be used to deal with nonlinear equation, however, EKF algorithm is not applicable in some occasions for linearization error, and the PF algorithm is not restricted by linearization error or Gaussian noise, which is applicable to any dynamic state space model, and can be used in filtering process.

The particle filter algorithm [11,12] is an estimation method based on Monte Carlo method and recursive Bayesian estimation. Its core idea is that: firstly, random samples are generated by state space, random sample is also called particle, secondly. The particle weight and position of the particle distribution are constantly adjusted through measurement value. Finally, the optimal estimation process is obtained by calculating the sample mean.

To facilitate the simulation positioning tracking results demonstrate, this paper considers two-dimensional case, the target is in line with Singer model in y direction, and uniform motion model without error in x direction.

State equation of hybrid system can be represented as:

$$\boldsymbol{X}_k = \boldsymbol{A}\boldsymbol{X}_{k-1} + U_{k-1}, \quad (2)$$

where $\boldsymbol{X}_k = [x(k), \dot{x}(k), y(k), \dot{y}(k), \ddot{y}(k)]^T$, $x(k), \dot{x}(k)$ denote respectively coordinates and velocity of moment target in the x direction, $y(k), \dot{y}(k), \ddot{y}(k)$ denote respectively coordinates, velocity and acceleration in the y direction.

State transition matrix is:

$$\boldsymbol{A} = \begin{bmatrix} 1 & T & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & T & (\alpha T - 1 + e^{-\alpha T})/\alpha^2 \\ 0 & 0 & 0 & 1 & (1 - e^{-\alpha T})/\alpha \\ 0 & 0 & 0 & 0 & e^{-\alpha T} \end{bmatrix}. \quad (3)$$

State noise covariance matrix is:

$$\boldsymbol{Q} = E[U_k U_k^T] = 2\alpha\sigma_m^2 \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & q_{11} & q_{12} & q_{13} \\ 0 & 0 & q_{21} & q_{22} & q_{23} \\ 0 & 0 & q_{31} & q_{32} & q_{33} \end{bmatrix}, \quad (4)$$

$$q_{11} = \frac{1}{2\alpha^5}(1 - e^{-2\alpha T} + 2\alpha T + \frac{2\alpha^3 T^3}{3} - 2\alpha^2 T^2 - 4\alpha T e^{-\alpha T}),$$

$$q_{12} = q_{21} = \frac{1}{2\alpha^4}(e^{-2\alpha T} + 1 - 2e^{-\alpha T} + 2\alpha T e^{-\alpha T} - 2\alpha T + \alpha^2 T^2),$$

$$q_{13} = q_{31} = \frac{1}{2\alpha^3}(1 - e^{-2\alpha T} - 2\alpha T e^{-\alpha T}),$$

$$q_{22} = \frac{1}{2\alpha^3}(4e^{-\alpha T} - 3 - e^{-2\alpha T} + 2\alpha T),$$

$$q_{23} = q_{32} = \frac{1}{2\alpha^2}(e^{-2\alpha T} + 1 - 2e^{-\alpha T}),$$

$$q_{33} = \frac{1}{2\alpha}(1 - e^{-2\alpha T}),$$

where α denotes maneuvering frequency, T denotes sampling interval, σ_m^2 denotes target acceleration variance.

Observation equation of hybrid system can be represented as:

$$\boldsymbol{Y}_k = H(\boldsymbol{X}_k) + \boldsymbol{V}_k, \quad (5)$$

where

$$H(\boldsymbol{X}_k) = \begin{bmatrix} \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} + b_u \\ \sqrt{(x_D - x_u)^2 + (y_D - y_u)^2 + (z_D - z_u)^2} + b_u + b_D \end{bmatrix}.$$

4 PF algorithm for hybrid positioning system data filtering

Assuming that system state equation and observation Equation is expressed as:

$$\begin{cases} X_k = F(x_{k-1}) + U_{k-1} \\ Y_k = H(x_k) + V_k \end{cases}, \quad (6)$$

where X_k and Y_k denote respectively state vector and the observation vector at the time *k*, U_k and V_k denote respectively state noise and observation noise process.

The detailed description of particle filter algorithm for hybrid system can be summarized in following steps.

Step 1. Particle and weight set initialization. Produce $M \times l$ random sampling points by according to the distribution function of system noise, where l is vector dimension of state vector $X(k)$.Initialize the particle by overlap sampling points to $X(0)$, the initialization of weight is $1/M$, particle and weight can be given by:

$$p(X_0) = \left\{X_0^{(m)}, \omega_0^{(m)}\right\}_{m=1}^{M}. \quad (7)$$

Step 2. Update the time and measurement. The particle set $X_k^{(m)}$ at time k, and $X_k^{(m)} = X_0^{(m)}$, the predicted value $X_{k+1}^{(m)}$ of particles can be calculated by target motion model at time $k+1$. In addition, when the particles predicted value $X_k^{(m)}$ go to observation equation, we can calculate the observation value of each particle at time k.

Step 3. Importance sampling: weights of each particle can be obtained by:

$$\omega_{k+1}^{(m)} = p(Z_{k+1} \mid X_{k+1}^{(m)}). \quad (8)$$

Then the weight is normalized:

$$\omega_k^{(m)} = \frac{\tilde{\omega}_k^{(m)}}{\sum_{m=1}^{M} \tilde{\omega}_k^{(m)}}.$$

Step 4. Determine resampling: calculate effective sample size

$$M_{eff}, M_{eff} = \frac{M}{1 + Var(\tilde{\omega}_k^{(m)})}.$$

If $M_{eff} < M$, need resampling, on the contrary, go to the next step.

Step 5. Resampling: when the total number of particles is constant, we can re-election weights of large particles, and give up the weights of small particles. After the change of particles, the weights of particles can be rewritten as $\omega_{k+1}^{(m)} = 1/M$.

Step 6. Statistical target location: The particle and weight of X_{k+1} can be expressed as:

$$p(X_{k+1}) = \left\{X_{k+1}^{(m)}, \omega_{k+1}^{(m)}\right\}_{m=1}^{M}. \quad (9)$$

The state estimation can be updated as follows:

$$X(k+1) = \sum_{m=1}^{M} X_{k+1}^{(m)} \cdot \omega_{k+1}^{(m)}. \quad (10)$$

Thus, repeat above iteration steps, these can realize position tracking.

5 The simulation results

Under the new integrated navigation system combining GPS and DTMB, in order to comparison and analysis verification the tracking effect of PF algorithm, this paper separately chooses 10 particles and 20 particles to simulate, and assumes that moving target is a car in urban environment, 3 GPS satellite signals and 3 DTMB station signals has been adopted in the integrated navigation system. Moreover, the target is in line with Singer model in y direction, and uniform motion model without error in x direction. The initial position for moving target is (4000,0), initial speed of x direction is 14m/s, initial speed of y direction is 11m/s. Initial acceleration of y direction is 0, in the process of movement, acceleration variance is 3.5, manoeuvring frequency is 0.1. The total observation time is 100s with interval in 1s, the initial state vector of car is $X(0) = [4000, 14, 0, 11, 0]^T$.The observation error of GPS and DTMB are both obey to Gaussian distribution, and the mean is 0, the standard deviation is 150m and 50m respectively. The simulation results are shown in Figure 2, Figure 3, and Table 1.

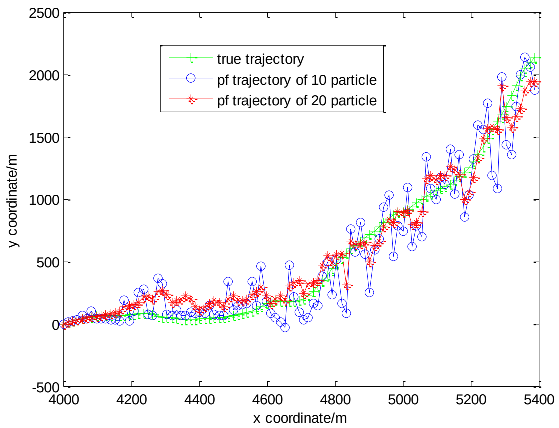

FIGURE 2 Positioning tracking trajectory based on PF under different number of particles

From the simulation results, we known that Figure 2 shows the filtering trajectory of PF algorithm is fluctuation near the real trajectory, and the volatility of 20 particles is larger than 10 particles, filtering trajectory is essentially consistent with true trajectory, moreover, tracking filtering effect of 20 particles is better than that of 10 particles.

Figure 3 depicts the change range of position error is about 100m in 20 particles, and 150m in 10 particles, in addition, the error change range of 10 particles is big, in the observation time of sixtieth and ninetieth, the position error is about 500m, however, the error change range of 20 particles is 0m to 250m, thus verify the tracking accuracy of 20 particles is higher than 10 particles.

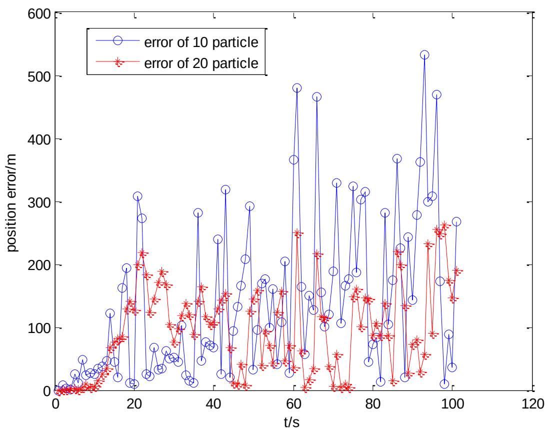

FIGURE 3 The positioning error under different number of particles

Table 1 depicts that when there is 10 particles, the mean is 138.6599. The standard deviation is 126.2985. When there is 20 particles, the mean value of 97.3565, the standard deviation is 70.6565. Thus the particle number is larger, the mean and standard deviation is smaller.

TABLE 1 Comparation of mean and standard deviation

Particle number	Mean(m)	Standard deviation (m)
PF(10 particles)	138.6599	126.2985
PF(20 particles)	97.3565	70.6565

Therefore, the simulation results show that the filtering tracking effect is good in the hybrid positioning system combing GPS and DTMB in the urban environment, in addition, the more the particle number, the smaller position error, the higher positioning accuracy, the better the position performance.

6 Conclusion

In this paper a new hybrid positioning method which combines GPS and DTMB is presented in the urban environment, and the hybrid positioning system model is also presented. In addition, particle filter algorithm has been derived in combination equation with nonlinear characteristics, under two groups of different number of particles, we simulate the tracking effect base on PF algorithm. The simulation results show that the more particle number, the higher positioning accuracy, the better location tracking effect. DTMB as GPS pseudolite can participate in joint positioning, which can compensate for the lack of DTMB station resources shortage, furthermore, improve the efficiency of navigation positioning through the enhancement of satellite navigation system in urban environment. The study provides a great reference value for further in-depth study of multiple source signals integrated positioning system. Therefore, it can be demonstrated that the presented novel method opens a new possibility for integrated positioning in urban environment.

Acknowledgments

This work was supported by Nature Science Foundation of Yunnan Province Education Department under Grant 2013Y017, Youth Project Foundation of Science and Technology Department of Yunnan Province in 2014 about “The seamless positioning technology research of nonlinear filtering algorithm in GPS/DTMB integrated navigation system” under Grant 2014FD048.

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Authors

Anhong Tian, October, 1984, Guizhou, China.

Current position, grades: lecturer at School of Computer Science and Engineering, Qujing Normal College, China.
University studies: Master degree in Chongqing university of posts and telecommunications, in 2010.
Scientific interest: data fusion, radio navigation and positioning.
Publications: 20 papers.

Chengbiao Fu, May, 1982, Yunnan, China.

Current position, grades: teaching assistant at School of Computer Science and Engineering, Qujing Normal College, China.
University studies: Master degree in Chongqing university of posts and telecommunications, in 2009.
Scientific interest: embedded system, internet of things, radio navigation and positioning.
Publications: 12 papers.