The vehicle navigation system based on the Calman filtering

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Abstract

In GPS dynamic filter, Wiener filter and Calman filter are two classical filtering methods. Among them, Calman filter is a time domain state space method, which is suitable to deal with multi variable system and time varying system, and the non-stationary random process, is a kind of excellent linear filter. In this paper, using MATLAB to achieve the Calman filter simulation, using a simulation experiment to prove that the Calman filter processing GPS data can improve the positioning accuracy.

Keywords

GPS, Calman filter, observation noise, MATLAB

1. Development status of vehicle navigation technology

The vehicle navigation system is similar to the space navigation system, which uses some relatively simple principles, such as the gyroscope, the mileage meter, compass and so on to realize the measurement of the speed, direction and displacement of the car. Then with the digital map matching, through a certain fusion algorithm, to solve the car's current position and displayed on the map.

At present the mainstream for vehicle location positioning technology may have four kinds: Global Positioning System (GPS), dead reckoning (DR) system and inertial navigation system (INS) and map matching (mm) system. The GPS system is the most widely used and most well-known system GPS has a global, all-weather, high precision, real-time three-dimensional measurement of the position and speed of the ability, so it has a great advantage. But the GPS system has its fatal weakness, GPS must be in the unoccluded satellite signals can provide accurate location services, and in real life many high-rise buildings, trees, tunnels and signal interference hindered the satellite signal accepted makes the GPS can not also receive satellite signals from at least four satellites.

When the GPS receiver can not receive the valid information, it is necessary to calculate the error of GPS data. The common solution method has the least square method, the Calman filter method and so on. The least square method can only use the current view measurement, can not handle the error of the observation data, so the positioning result is affected greatly by the view measurement, and the accuracy is not high. Calman filter does not need to store a large amount of data, to facilitate the processing of real-time data. It is an optimal auto regressive data processing algorithm, which can calculate the latest filtering value, which is convenient for real-time processing of the observed data, and provides an optimal estimation value. Therefore, Calman filter is widely used, and plays a key role in GPS positioning.

2. GPS navigation and positioning principle

Global positioning system (GPS) is one of the important achievements in twentieth Century, which can provide users with continuous real-time, high precision 3D position and time benchmark. GPS mainly has three major components: GPS satellite (space constellation part), ground support system (ground control system) and GPS receiver (user part). Space constellation consists of 24 satellites, these satellites are distributed in 6 orbits, each of which has 4 satellites in orbit. Satellite orbit relative to earth's equatorial plane inclination to 55 degrees, the orbital plane of the ascending node equatorial difference of 60 degrees and in the adjacent tracks, satellite exchange angular difference of 30 degrees. The average height of orbit about 20200KM satellite operation cycle 11h58min.

Therefore, the same observation station daily satellite distribution graph of the same, just a day ahead of time 4min, each satellite every day about 5h above the horizon, and at the same time, the number of satellites above the horizon varies with the time and place, at least for 4 star, up to 11 satellites. This ensures that at least 4 satellites are at any time at any point in the earth. At the same time, the propagation of the satellite signal is not affected by the weather, so that GPS becomes a global, all-weather continuous real-time positioning system. The basic function of the GPS satellite is to receive and store the navigation information sent by the ground control station, and to receive and execute the command of the ground control station. Satellite on a microprocessor, can be part of the data processing, satellites can also by satellite borne high-precision cesium clock and rubidium clock to provide accurate time standard and, the satellite can also be sent to user navigation and positioning information.

Ground control station is mainly through the adjustment of satellite attitude and enable the operation of spare satellites. The monitoring station is in the master station under the direct control of the data automatic collection centers, stations are equipped with a dual frequency receiver, high-precision atomic clock, computer and some environmental sensor data. The receiver through the continuous observation satellite, data acquisition, monitoring the status of the satellite, and ultimately the data back to the user; the atomic clock to provide time standard; environmental sensors to collect local meteorological data. All data from the computer storage and preliminary processing, then sent to the master station, used to determine the satellite orbit.

The main task of the user receiving part is to receive the signals transmitted by the satellite in order to obtain the necessary navigation and positioning information and the concept of measurement, and through the data processing to complete the navigation and positioning work. This is the basic principle of GPS navigation and positioning.

3. Error Origin of GPS

Although GPS navigation and positioning system has a relatively high accuracy, but due to various reasons, there are still a lot of GPS error. GPS is the main source of error: (1) with the satellite related errors: satellite ephemeris error, satellite clock error, SA error, relativistic effects; (2) and route of transmission error related: ionospheric delay, tropospheric delay, multi path effect; (3) and GPS receiver error, receiver clock error, receiver position error, the receiver antenna phase center deviation.

These three kinds of error sources mainly influence the measurement of electromagnetic wave propagation time and the precise location of the satellite. The so-called precision positioning, which is the use of a variety of models to estimate a variety of errors, and then modify the GPS positioning results of the technology, it is the forefront of GPS applications.

4. Calman filter principle

GPS contains and satellite related errors, and communication pathway related error and with errors related to GPS receiver, and for the random errors caused by satellite measurements, best is filtered so as to improve the accuracy. Filtering is a process of signal processing and transformation, it can be achieved through hardware, can also be achieved through software, Calman filter is a kind of software filtering processing method. The basic idea is: according to the minimum mean variance optimal estimation criterion by the state space model of the signal and noise, a moment ago were estimated using value and the present observations to update estimates of the state variables are, at the moment are estimated, the algorithm according to the establishment of Department of system equation and the observation equation on the need to deal with the signal make meet the minimum mean square error estimation.

Calman filter is a recursive filtering algorithm based on state space method. In the state space method, the concept of state variable is introduced. In practical application, it can reflect the characteristics, characteristics and conditions of the system by selecting appropriate state variables. The model of Calman filter includes state space model and observation model. The state is a model that reflects the law of state change, and describes the state transition of the neighboring time by the state equation. The observation model reflects the relationship between the actual observation and the state variables. Calman filtering is the optimal estimation of the state of the system with joint observation information and state transition rule. It provides a solution to the state estimation problem under discrete time control, which can be expressed by the following linear stochastic differential equation of state:

$$X_K = \phi_K X_{k-1} + \mathrm{BU}_{K-1} + \mathrm{W}_{K-1} \tag{1}$$

The measurement equation of the system is:

$$Z_K = HX_K + V_K \tag{2}$$

Among them, it is the system state of K time, and is the control quantity of K time to the system. And B system parameters, for the multi model system, H for the matrix. Random variables and representative processes and measurement errors. These errors are assumed to be Gauss white noise, both of which are independent of each other, and their covariance are Q, R, and have the probability distribution as follows：

$$p(w) \sim N(0,\ \mathrm{Q}) \tag{3}$$

$$p(v) \sim N(0,\ \mathrm{R}) \tag{4}$$

In practice, the process noise covariance matrix Q and measurement error covariance matrix R will be continuously changing with time and measurement. But here we assume that they are constant. This is the premise of the calculation of Calman filter.

Calculation process of Calman filter:

(1) Calculated state estimate:

$$\hat{X}(t+1|t+1) = \hat{X}(t+1|t) + K(t+1)\varepsilon(t+1) \tag{5}$$

(2) Calculated state prediction:

$$\hat{X}(\mathrm{t}+1|t) = \phi\,\hat{X}(t|t) \tag{6}$$

(3) Computing information:

$$\varepsilon(t+1) = Y(t+1) - H\,\hat{X}(t+1|t) \tag{7}$$

(4) Calman filter gain:

$$K(t+1) = P(t+1|t)H^T[HP(t+1|t)H^T + R]^{-1} \tag{8}$$

(4) Calculate one step prediction mean square error:

$$P(t+1|t) = \phi P(t|t)\phi^T + \Gamma Q \Gamma^T \tag{9}$$

(5) Calculating the mean square error of the estimated mean square:

$$P(t+1|t+1) = [I_n - K(t+1)H]P(t+1|t) \tag{10}$$

5. Application of Calman filter in GPS positioning error

Using Calman filter to process dynamic data, we first establish the state equation and observation equation of filter, and give the longitude, latitude and altitude of the GPS receiving system. In general, the geographic coordinate system is converted to the earth right angle coordinate system, and the position, velocity, acceleration, error and other information of the receiver in the 3 coordinate axes are defined in the sequence.

$$X = [x\ \dot{x}\ \ddot{x}\ \varepsilon_x\ \mathrm{y}\ \dot{y}\ \ddot{y}\ \varepsilon_y\ \mathrm{z}\ \dot{z}\ \ddot{z}\ \varepsilon_z] \tag{11}$$

The $x\ \dot{x}\ \ddot{x}\ \varepsilon_x\ y\ \dot{y}\ \ddot{y}\ \varepsilon_y\ z\ \dot{z}\ \ddot{z}\ \varepsilon_z$ respectively in the three state motor carrier axis position, velocity, acceleration and the position error. Usually a first-order Markov process representation of each position error, the position error of the total can be regarded as a colored noise.

The system equation can be written as:

$$\dot{X}(t) = AX(t) + U(t) + W(t) \tag{12}$$

Among them, the system state transition matrix is:

$$A = \begin{bmatrix} A_X & 0_{4\times} & 0_{4\times4} \\ 0_{4\times4} & A_Y & 0_{4\times4} \\ 0_{4\times4} & 0_{4\times4} & A_Z \end{bmatrix} \tag{13}$$

Set up observation equation:

$$U(t) = [0\ 0\ {}^{a_x}\!/\!{}_{\tau_{ax}}\ 0\ 0\ 0\ {}^{a_y}\!/\!{}_{\tau_{ay}}\ 0\ 0\ 0\ {}^{a_z}\!/\!{}_{\tau_{az}}\ 0\ ]^T \tag{14}$$

$$W(t) = [0\ 0\ \omega_{ax}\ \ \omega_x 0\ \ 0\ \omega_{ay}\ \ \omega_y\ \ 0\ 0\ \omega_{az}\ \ \omega_z\ ]^T \tag{15}$$

The positioning of GPS receiver output results for x_0, y_0, z_0, then in which respectively, including the true state of x, y, z and first-order Markov process error of $\varepsilon_x, \varepsilon_y, \varepsilon_z$ and the amount of measured error of $\omega_{b_x}, \omega_{b_y}, \omega_{b_z}$.

$$\begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} + \begin{bmatrix} \omega_{b_x} \\ \omega_{b_y} \\ \omega_{b_z} \end{bmatrix} \tag{16}$$

6. Simulation experiment

In order to simplify the model, the vehicle is assumed to travel along a straight line, and the starting point of the vehicle is the coordinate origin. Set sampling time for the T_0, with $s(k)$ said in the vehicle at the sampling time $k(T_0)$ of the real location, with $y(k)$ at the moment GPS $k(T_0)$ location of the observed value, then there is the observation model:

$$y(k) = s(k) + v(k) \tag{17}$$

Among them, $v(k)$ said the GPS positioning error,hypothesis as a zero mean, variance is σ_v^2 of white noise, variance σ_v^2 by a large number of GPS observations with experimental data with statistical method, acquisition, vehicle speed is denoted $\dot{S}(k)$, the acceleration is $a(k)$, a uniform acceleration motion formula is:

$$s(k+1) = s(k) + \dot{S}(K)T_0 + 0.5T_0^2 a(k) \tag{18}$$

$$\dot{s}(k+1) = \dot{s}(k) + T_0 a(K) \tag{19}$$

The acceleration of $a(K)$ is composed of two parts, $u(k)$ and random acceleration $w(k)$,that is

$$a(k) = u(k) + w(k) \tag{20}$$

Among them, $u(k)$ is known as a mobile signal; $w(k)$ is caused by the ground friction and wind random acceleration, assuming that it is zero mean, variance of ${\sigma_w}^2$ independent of the $v(k)$ white noise, defined as $x(k)$ for the location and speed of the car, that is

$$x(k)=\begin{bmatrix} s(k) \\ \dot{s}(k) \end{bmatrix} \tag{21}$$

The equation of state of the vehicle motion can be obtained:

$$\begin{bmatrix} s(k+1) \\ \dot{s}(k+1) \end{bmatrix}=\begin{bmatrix} 1 & T_0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} s(k) \\ \dot{s}(k) \end{bmatrix}+\begin{bmatrix} 0.5{T_0}^2 \\ T_0 \end{bmatrix}u(k)+\begin{bmatrix} 0.5{T_0}^2 \\ T_0 \end{bmatrix}w(k) \tag{22}$$

The observation equation is:

$$y_k=\begin{bmatrix} 1 & 0 \end{bmatrix}\begin{bmatrix} s(k) \\ \dot{s}(k) \end{bmatrix}+v(k) \tag{23}$$

The state space model of the system is:

$$\begin{aligned} x(k+1) &= \Phi x(k)+Bu(k)+\Gamma w(k) \\ y(k) &= Hx(k)+v(k) \end{aligned} \tag{24}$$

Among them, $\Phi=\begin{bmatrix} 1 & T_0 \\ 0 & 1 \end{bmatrix}$, $B=\Gamma=\begin{bmatrix} 0.5{T_0}^2 \\ T_0 \end{bmatrix}$ and $H=\begin{bmatrix} 1 & 0 \end{bmatrix}$, So, the model of the vehicle GPS navigation and positioning Calman filtering problem is: Based on the GPS observation data $(y(1), y(2), ...y(k))$ to get the best estimate $\hat{s}(k \mid k)$ of the position $s(k)$ of the car in the moment K .

Without considering the dynamic factors of the maneuvering target ($u(k)=0$), the vehicle will be extended to the thinking of uniform linear motion,that is

$$X(k)=[x(k)\ \hat{x}(k)\ y(k)\ \hat{y}(k)]^T \tag{25}$$

When the state contains the position, velocity, and longitudinal position and velocity of the horizontal direction, the system equation can be expressed by the following formula.

$$\begin{bmatrix} x(k) \\ \hat{x}(k) \\ y(k) \\ \hat{y}(k) \end{bmatrix}=\begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & T \end{bmatrix}\begin{bmatrix} x(k-1) \\ \hat{x}(k-1) \\ y(k-1) \\ \hat{y}(k-1) \end{bmatrix}+\begin{bmatrix} 0.5T^2 & 0 \\ T & 0 \\ 0 & 0.5T^2 \\ 0 & T \end{bmatrix}\omega_{2\times1}(k) \tag{26}$$

$$Z(k)=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}\begin{bmatrix} x(k) \\ \hat{x}(k) \\ y(k) \\ \hat{y}(k) \end{bmatrix}+v_{2\times1}(k) \tag{27}$$

Assume that the car is moving on a two dimensional level, initial position (-100m, 200m), the horizontal movement speed is 2m/s, the movement speed of the vertical direction is 20m/s, the scan period of GPS receiver is T=1s, the mean value of observation noise is 0, The variance is 100.The smaller the process noise, the more close to the uniform linear motion of the target, on the contrary, for the curve movement. The following results are obtained by simulation.

In Fig. 6.1, the observed trajectory is obviously in the oscillation, which shows that the measurement noise is very large, and after the Calman filter, the filter estimate is closer to the true trajectory of the target.

Figure 6.2 can be seen in the displacement observation noise maxima close to 35m, for moving target site (ca. 1800 m, width of about 250 m), the noise is very large, of course, this is only limited to the simulation, actual sensor measurement errors impossible so big. After Calman filter, the position error is reduced to below 10m, it can be seen that although Calman filter can not completely eliminate the noise, but it has been to maximize the impact of reducing noise.

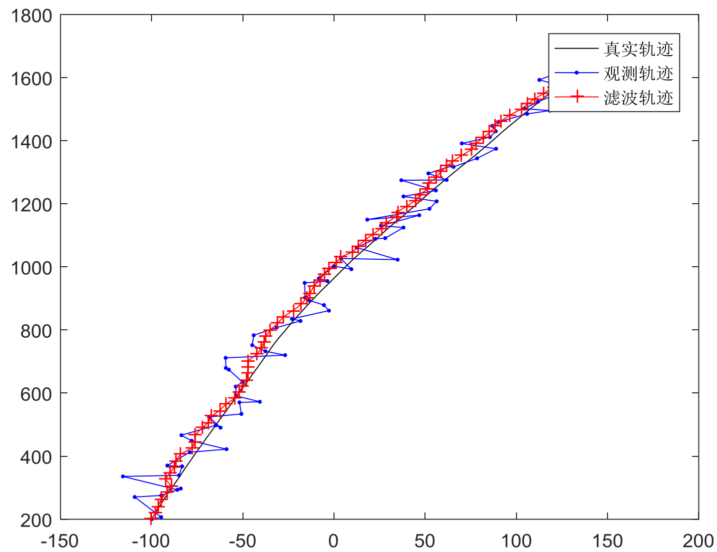

Fig. 6.1 Trace trace

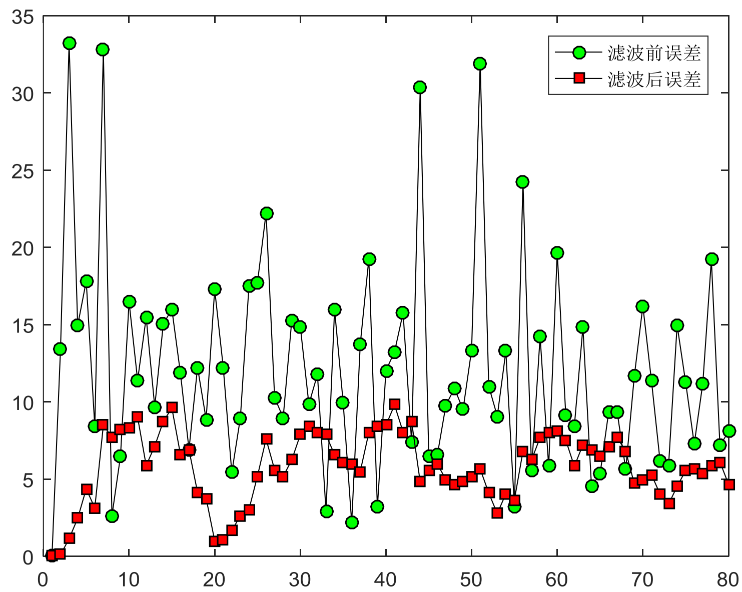

Fig. 6.2 Tracking error chart

7. Summary

A Calman filtering process is equivalent to a combination of a given observation value and a prediction model. In this process, the observed value is equivalent to the existing theoretical model, and the specific observation and theoretical model of the credibility of the observation noise and measurement noise to quantify. Contains a large number of errors in GPS observations, this paper mainly aiming at the process of Kalman filter in GPS vehicle navigation was simulated, and the according to the minimum mean variance optimal estimation criterion, using the state space model of the signal and noise, were estimated using a moment ago value and the present observations to update estimates of the state variables, and current estimates. The results show that Calman filter can reduce the influence of noise to the greatest extent, and it is a more reasonable method of data processing.

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