Research on the MINS navigation method of the vehicle based on satellite assistance

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Abstract. Aiming at the problem of excessive positioning error caused by Global Navigation Satellite System (GNSS) lock-out in vehicle navigation, this paper proposes a vehicle integrated navigation method based on GNSS-assisted Micro Inertial Navigation System (MINS). This method introduces state feedback and uses the Kalman filter to perform information fusion to obtain the optimal estimation of system navigation information. Simulation results show that the algorithm can effectively suppress the divergence of strapdown solution errors, and at the same time make up for the error problem caused by GNSS loss of lock. It is worth mentioning that among the inertial devices, low-cost, medium-precision Micro Electro Mechanical System (MEMS) devices can be selected. After the integrated navigation algorithm, the navigation results can reach higher accuracy, which has certain engineering application value. This method not only ensures the accuracy of vehicle positioning but also greatly reduces the cost of navigation devices.

Keywords: Vehicle navigation, Vehicle navigation based on Global Navigation Satellite System (GNSS), Inertial Navigation System (INS), Integrated navigation

1. INTRODUCTION

Due to the development of China's transportation industry and the requirements for building intelligent transportation systems, the development of intelligent vehicles has received increasing attention [1]. Regardless of the safe communication between intelligent vehicles or the support of the traffic safety system, accurate positioning plays a vital role. Global Navigation Satellite System (GNSS) and on-board inertial sensor integration are some of the solutions for vehicle self-localization [2]. At present, the mainstream in-vehicle navigation system is the Global Navigation Satellite System (GNSS), but its anti-interference is poor and it is prone to loss of lock [3]and other problems. Information fusion between the Inertial Navigation System (INS) is a self-combined technique which can provide position and attitude solution with a high update rate. INS and GNSS On the one hand, it can improve the positioning accuracy of GNSS, on the other hand, it can make up for the errors caused by GNSS loss of lock, and reduce the error accumulation of INS. Traditional INS uses high-level Inertial Measurement Units (IMUs), which are expensive and not suitable for the civilian automotive industry. MEMS sensors are relatively low in price, small in size, easy to install, integrate, and intelligent, and have large application fields. Therefore, MEMS-based INS / GNSS integrated navigation is more practical [4]and more in line with the needs of future development.

To improve the accuracy of intelligent vehicle navigation and positioning, Yongsong Zou used dual GPS to improve the positioning accuracy by improving the extended Kalman algorithm [5]; Zeyu Sun combined GNSS with dead reckoning to improve the stability of the navigation system, but the positioning error Will increase with the length of the signal loss time [6]; Yahui Liu and others based on the INS / GPS integrated navigation method, proposed an adaptive Kalman filtering method, which improves the accuracy of the algorithm [7]. In this paper, the information fusion of GNSS and MINS is introduced, the state feedback is introduced, the information fusion is performed by Kalman filtering, and the relative speed and position information can be obtained by using the low-precision inertial unit, which greatly reduces the cost and ensures the accuracy. Claim. On this basis, a simulation model of the integrated navigation system is built, and simulation experiments are performed. The overall performance and algorithm of the navigation system are tested and analyzed. The experimental results prove the correctness of the navigation algorithm and model.

2. REFERENCE COORDINATE SYSTEM OF INTEGRATED NAVIGATION SYSTEM

The inertial navigation system usually adopts the fixed right-hand rectangular coordinate system, and the commonly used coordinate system is as follows:

- Epicenter inertial system $O_i x_i y_i z_i$ (i System).

It is a relative inertial space, which does not rotate with the earth and will not be affected by the sun's motion. It takes the earth's center of mass as the origin O_i, two stars as the x_i and y_i axes, and the earth's polar axis as the z_i axis.

- Earth coordinate system $O_e x_e y_e z_e$ (e system)

It is also called the earth fixed coordinate system. Its main feature is that it rotates with the earth and is closely connected with the earth. The e-system rotates relative to the i-System, and its rate is the angular rate of the earth's rotation axis, w_e = 15.04107 ° / h. It takes the earth center as the origin O_e, the earth polar axis, 0 ° longitude, and 90 ° longitude as x_e, y_e, and z_e axes..

- Navigation coordinate system $O_n x_n y_n z_n$ (n system)

The purpose of setting up this coordinate system is to describe the information of INS calculation conveniently. Generally, $O_t x_t y_t z_t$ is chosen as the navigation coordinate system.

- Carrier coordinate system $O_b x_b y_b z_b$ (b system)

It is also called an elastic coordinate system. It takes the center of the carrier body as the origin O_b, the transverse axis of the carrier as the x_b axis, the longitudinal axis of the carrier as the y_b axis, and the plane of the carrier upward as the z_b axis [8].

In this paper, the state equation and measurement equation of the SINS/satellite integrated navigation system is established by using a navigation coordinate system. The schematic diagram of some coordinate systems is shown in **Fig. 1**.

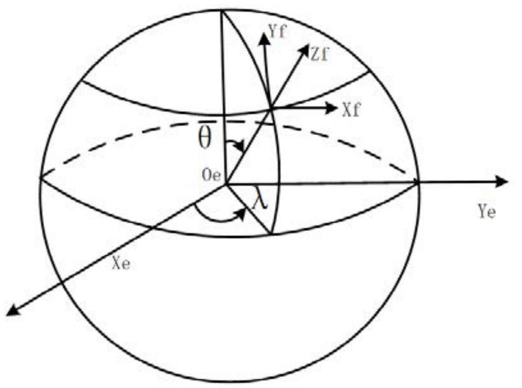

Fig. 2 Partial coordinate system diagram

3. GNSS/MINS INTEGRATED NAVIGATION MODEL

3.1. Principle of Integrated Navigation System

Inertial/Satellite matching integrated navigation is composed of an inertial navigation system, satellite, and solution computer. Its essence is that in the process of motion, according to the position output of the inertial navigation system, the measured value of the satellite is used for correction, and then the Kalman filter is used for fusion, to achieve the purpose that the positioning result of the navigation system is close to the real value, to reduce the accumulated error of the strapdown inertial navigation system.

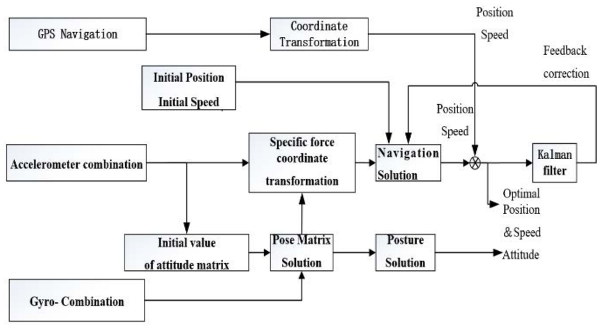

Fig. 1 Schematic diagram of integrated navigation system

There are two types of INS/SAT integrated navigation systems: loose combination and tight combination [9]. Because the loose combination can realize the independent operation of inertial navigation and satellite, the combination structure is simple, and it is easy to realize in engineering. At the same time, it can also carry out information fusion navigation. The system schematic diagram is shown in **Fig. 2**.

3.2. State Equation of Integrated Navigation System

In the integrated navigation system, the establishment of a model is very important. The system state model in this paper is the error model of the inertial navigation system, the accelerometer of the inertial device, the superposition of the gyro modeling zero deviation, the gyro modeling zero deviation, and the white noise, and the 18-dimensional state equation is established.

$$\dot{X}(t) = F(t)X(t) + G(t)W(t) \tag{0}$$

Where the status variable is

$$X_{(t)} = \begin{bmatrix} \phi_x & \phi_y & \phi_z & \delta v_x & \delta v_y & \delta v_z & \delta_x & \delta_y & \delta_z \\ \varepsilon_x & \varepsilon_y & \varepsilon_z & \nabla_x & \nabla_y & \nabla_z \end{bmatrix} \tag{2}$$

Among them, ϕ_x , ϕ_y , ϕ_z is the strapdown inertial navigation mathematical platform misalignment angle, δv_x , δv_y , δv_z is the velocity error on three axes of the inertial system at the starting point, δ_x , δ_y , δ_z is the position error, ε_x, ε_y, ε_z is the gyro constant drift, and ∇_x, ∇_y, ∇_z is the accelerometer constant bias.

3.3. Observation Equation of Integrated Navigation System

The observation equation of the integrated navigation system consists of three parts: position observation, velocity observation, and satellite phase observation equation [10], which can be obtained as follows:

$$Z(t) = HX(t) + V \tag{3}$$

In formula, $Z_{(t)} = \left(Z_P \quad Z_V \quad Z_B\right)^T$, in which,

$$Z_P = \begin{bmatrix} lati_{last} - lati_{com} \\ h_{last} - h_{com} \\ longi_{last} - longi_{com} \end{bmatrix} \tag{4}$$

$$Z_V = \begin{bmatrix} vn_{last} - vn_{com} \\ vu_{last} - vu_{com} \\ ve_{last} - ve_{com} \end{bmatrix} \tag{5}$$

$$H = diag\left(H_P \quad H_V \quad H_B\right)^T \tag{6}$$

V is the observation noise, and the simulation sets the reference actual device error.

$$V = diag\left(V_P \quad V_V \quad V_B\right)^T \tag{7}$$

3.4. Establishment of Combined System Filter

The filtering algorithm with high precision can effectively improve the navigation accuracy of the integrated navigation system. In this paper, the standard Kalman filtering method commonly used in engineering is used, and the feedback correction filter is used for the simulation experiment. According to the principle of minimum variance estimation, Kalman filter estimates the state of the system containing Gaussian noise through the recursive process, which is less in data storage and calculation, which is more conducive to online operation calculation [11]. Kalman filtering includes three aspects: system model, observation model, and filtering algorithm, which are also the core part.

Its system model and observation model are:

$$\begin{cases} \dot{X}(t) = F(t)X(t) + G(t)W(t) \\ Z(t) = H(t)X(t) + V(t) \end{cases} \tag{8}$$

Where, *X(t)* is the state vector, *F(t)* is the state matrix, *G(t)*is the noise distribution matrix, and *W(t)* is the noise vector. *Z(t)* is the observation vector, *V(t)* is the observation matrix, *W(t)* and *V(t)* are independent vectors without certain correlation [12].

The working process of Kalman filter mainly includes two stages: prediction and update [13], and its main working process is as follows:

Covariance prediction:

$$P_{k,k-1} = FX_{k,k-1}FT + Q \tag{9}$$

Where, F is the system state transition matrix.

Kalman gain:

$$K = P_{k,k-1}H^{-1} / (HP_{k,k-1}H^{-1} + R) \tag{10}$$

Covariance update:

$$P_{k,k-1} = (I - KH)P_{k,k-1} \tag{11}$$

Status update:

$$X_{k,k} = X_{k,k-1} + K(Z_k - H_{k,k-1}) \tag{12}$$

Among them, $X_{k,k-1}$ is the forecast estimate term, $K(Z_k - H_{k,k-1})$ is the observation correction term.

The filtering process is shown in **Fig. 3**:

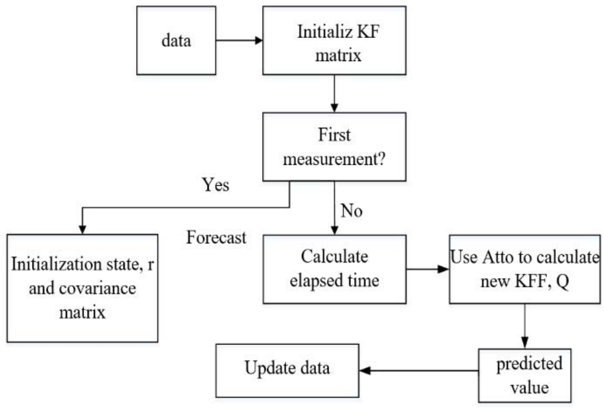

Fig. 3 Working process diagram of filter

4. SIMULATION ANALYSIS

The simulation program is designed with MATLAB software, and the following simulation experiments are carried out. The correlation error of noise is obtained from the previous simulation process.

4.1. Simulation Conditions

- The starting point of the unmanned vehicle is located at 40.030304 ° n, 116.355108 ° e, and the whole driving time is 373.53s.
- Sampling period: 5ms for gyro and accelerometer, 0.1s for satellite signal.
- Noise error: the white noise of gyro is (0.04 / (57 * 3600)) ^ 2, the low frequency random noise of gyro is (0.01 / (57 * 3600)) ^ 2, and the random noise of accelerometer is (1e-3) ^ 2.
- Error drift correlation time: gyro is 300 * ones (3,1), accelerometer is 1000 * ones (3,1).

4.2. Results and Analysis

The easting, northing, and skyward angles of SINS/satellite integrated navigation are shown in **Fig. 4**; the easting, northing position, and altitude covariances of SINS/satellite integrated navigation are shown in **Fig. 5**; the easting, northing, and skyward velocity covariances are shown in **Fig. 6**. (take the first 2000 groups of data).

In the strapdown inertial navigation system after integrated navigation by satellite, the first 10s of the easterly position covariance showed an attenuation trend, and the first 2s remained at 0.0004, then sharply declined, close to 0, and fluctuated between 0.0001 and 0.0002. There is a jump value in the early stage of the North position covariance, which is about 0.005, then rapidly decays to about 0.0002 within 2s, then slowly approaches 0, and fluctuates between 0.0001 and 0.0002. The height covariance has a large jump value in the early stage, at about 0.16, and then sharply attenuated to around 0.0001, and then slowly attenuated to close to 0.

There is a big jump value in the early stage (about 2 in the East, about 4 in the North), and then it is 0. The day-forward velocity covariance increased sharply to about 0.5 in the early stage, then decreased to about 0.3, and slightly fluctuated within the range of 0.3 to 0.6 after 1.5s.

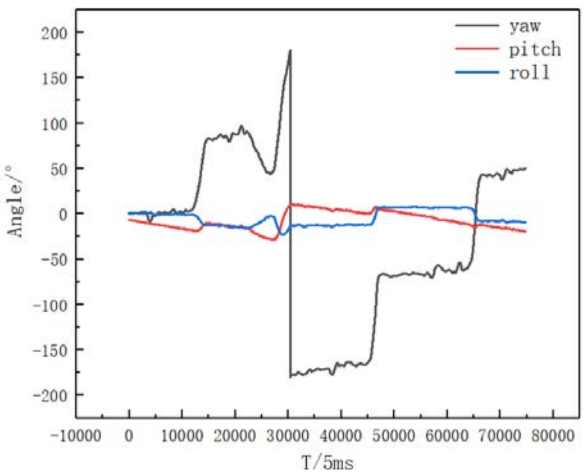

Fig. 4 Three-way deflection angle

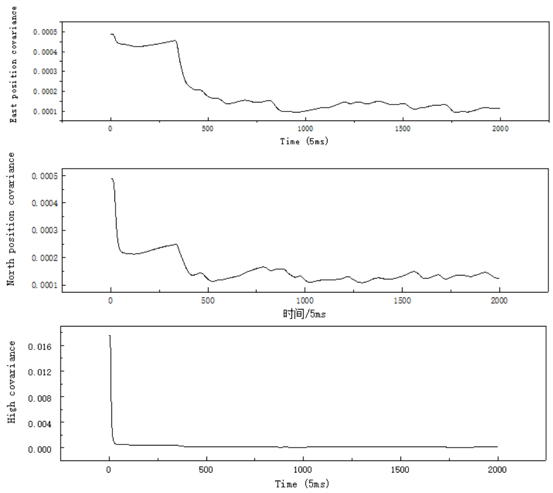

Fig. 5 Three-way position covariance

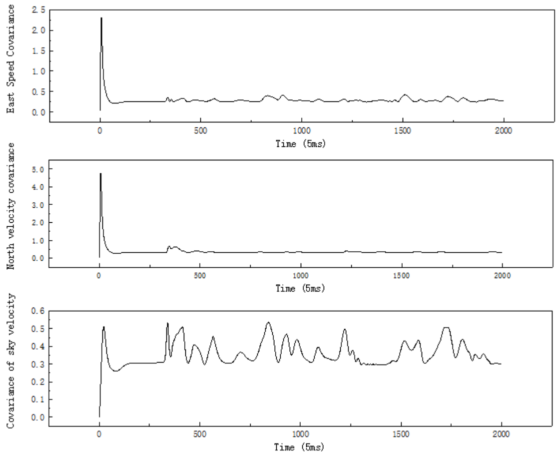

Fig. 6 Three-way velocity covariance

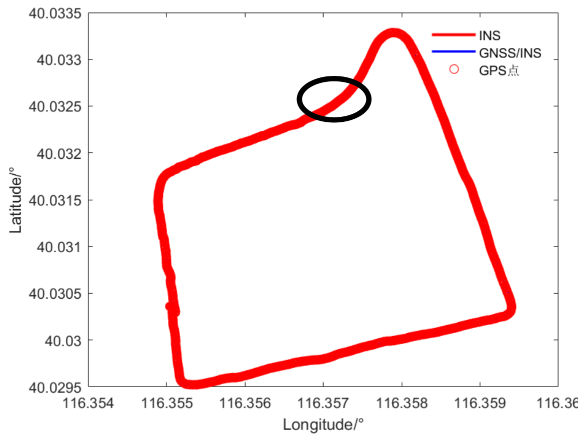

Fig. 7 Road map

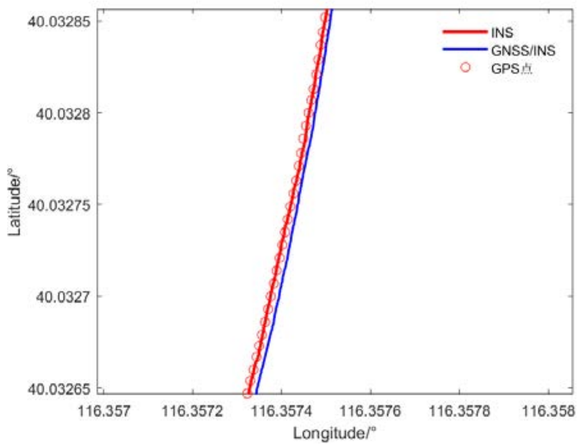

Fig. 8 Partial enlarged map of the route

The comparison of INS, GPS points, and combined navigation simulation routes is shown in **Fig. 7**, and the partial enlarged image of the comparison route is shown in **Fig. 8**.

From the local enlarged image of the comparison route, Comparing with both single INS and single coincided basically with the GPS route, the integrated navigation simulation route is consistent, and the error is very small, in the range of 0.001.

5. CONCLISION

Based on the information of satellite detection, the feasibility of a strapdown inertial / satellite integrated navigation method is verified. Based on the strapdown inertial navigation error equation, the state model of the system is established, and the satellite detection value is used as the measurement value. Only one observation expression is used, that is, the position and attitude information of the unmanned vehicle are included at the same time. In this paper, state feedback is introduced and Kalman filter with hybrid correction is used for information fusion to obtain the optimal estimation of system navigation information. Simulation results show that the algorithm can effectively suppress the divergence of Strapdown solution error. It is worth mentioning that MEMS devices with low cost and medium precision can be used as inertial devices. After integrated navigation, almost high precision can be achieved, which has certain engineering application value.

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