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Design of Strapdown Inertial Navigation System Based on MEMS

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ABSTRACT. *The development of strap-down inertial navigation system is becoming more and more mature. This paper proposes a design scheme of cheap inertial navigation system for satellite earth station based on MEMS. This article mainly expounds the principles and characteristics of strap-down inertial navigation, geomagnetic orientation, and micro-electromechanical systems. After considering their respective advantages, a filtering algorithm based on Kalman filtering is designed on this basis. This navigation system is combined to form a new combined system. Finally, the feasibility of the system is proved through experiments, which verifies the excellent characteristics and practical value of the system.*

KEYWORDS: *Inertial navigation, Attitude angle, Geomagnetic orientation, Kalman filtering, Integrated navigation system*

1. Introduction

1.1 Project research significance

Inertial navigation system (INS) is a navigation system based on Newton's classical mechanics, The linear acceleration and angular velocity of the carrier can be obtained by the inertial sensitive device, and the speed, position and posture of the carrier can be obtained by processing this information through integral operation.[1] The Strap-down Inertial Navigation System (SINS) is to directly install the inertial sensitive device on the carrier. It is necessary to ensure that the three-axis direction of the device is consistent with the three-axis direction of the carrier's movement, and then the carrier is established on this basis Coordinate System.[2] During the movement of the carrier, the gyroscope will move relative to the inertial system, and calculate the transformation relationship between the inertial system and the navigation coordinate system through the relative position of the carrier and the inertial system—the attitude matrix; at the same time, the accelerometer outputs The linear acceleration can be combined with the posture matrix to obtain the relative position of the navigation coordinate system, and finally the posture and orientation information of the navigation can be obtained through the integral operation.

And with the development of Micro Electromechanical System (MEMS), miniature gyroscopes and accelerometers with small size, light weight and low power consumption quickly occupy the market [3, 4], from being used in the military field to the civilian and commercial fields, it is also rapidly becoming popular, such as mobile phones and automobiles. Especially in harsh environments such as geological exploration, it can perform navigation tasks excellently without GPS signals. . And by virtue of the good autonomous navigation ability and high anti-interference ability of the inertial navigation system, it can be used without GPS signal. Coupled with the increasing accuracy, it has become the mainstream in the navigation system.

However, because the navigation results of inertial navigation are obtained through continuous integration, errors will gradually accumulate over time, which is not suitable for long-term high-precision navigation.[5] In order to solve this problem, the navigation information obtained by inertial navigation can be used in combination with other navigation methods, such as GPS navigation, geomagnetic positioning, visual positioning and radio positioning, so as to eliminate errors caused by integration.

Therefore, it is worthwhile to design a cheap strapdown inertial navigation system based on MEMS.

1.2 The main research content and chapter arrangement of this article

The core of this article is to design a set of cheap strapdown inertial navigation system based on MEMS, which has the obvious advantages of small size, low cost and high integration, and has obvious research value and significance. The content of the full text is arranged as follows:

First, it briefly introduces the research significance and the value of the subject, and then introduces the main content of this article. Then the basic operation principle of strapdown inertial navigation system is introduced. Aiming at the shortcoming of large error in long-term calculation, a solution method combining inertial navigation system and geomagnetic positioning is proposed.

Finally, the idea of Kalman filtering is used to process the calculated carrier position information, which further improves the calculation accuracy of the navigation system, and verifies the feasibility of the above algorithm through the swing table test.

2. Strapdown inertial navigation system principle and system combination

The inertial navigation system has the problem of inertial navigation error accumulating with time; and the magnetic signal is easily interfered by the constantly changing electric and magnetic signal sources in the environment, the positioning result is unstable, and the accuracy will be affected. Complementary based on their advantages can simultaneously solve the limitations of the two methods.

2.1 Principle of strapdown inertial navigation system

Different from the platform-type inertial navigation system, the strap-down inertial navigation system has the advantages of small size and light weight [5], while having a relatively simple system structure, it can also ensure higher accuracy and reliability.[6] Based on this, this article adopts strapdown inertial navigation system.

Taking into account the earth's rotation, it is necessary to convert multiple coordinate systems to ensure the accuracy of navigation and positioning.[7] Commonly used space coordinate systems include earth rectangular coordinate system, launching inertial coordinate system, geocentric inertial coordinate system, body coordinate system, data processing coordinate system and so on.[8]

In the strapdown inertial navigation system, the carrier will be fixed together with the inertial device and move together. The angular acceleration ω1 of the carrier coordinate system relative to the inertial system measured by the inertial device can be obtained by subtracting the angular velocity ω2 of the navigation coordinate system relative to the inertial system to obtain the relative angular velocity ω of the two coordinate systems, and the attitude matrix can have this relative angular velocity in real time Calculated. When the attitude matrix is known, the linear acceleration f1 obtained by the accelerometer can be transformed into the platform coordinate system, and the attitude angle can be directly calculated by the attitude matrix. The schematic diagram of the strapdown inertial navigation system is shown in Figure 1.

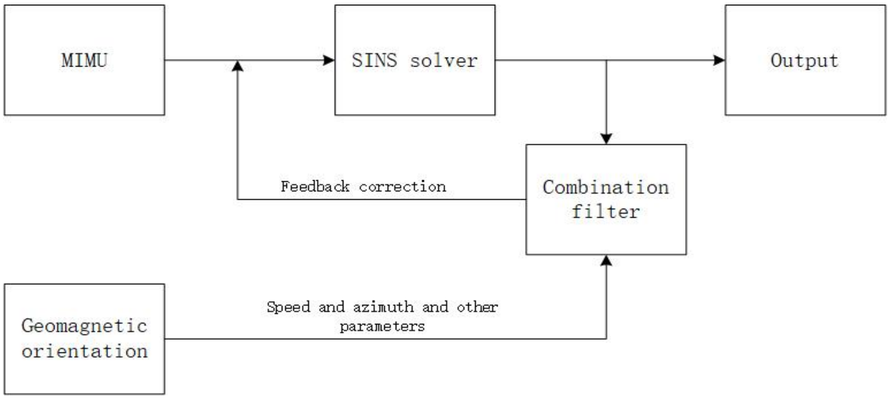


Figure. 1 Schematic diagram of strapdown inertial navigation system

2.2 Geomagnetic orientation

The realization of high-precision geomagnetic orientation is mainly based on two parts: magnetic interference error correction algorithm and attitude calculation algorithm.[9] There are two main factors affecting the accuracy of geomagnetic orientation: its own error and external magnetic interference. The data collected by the sensor can be analyzed through the error and interference correction algorithm, the compensation parameters of the current environment can be calculated, and then the correction can be performed to obtain more accurate data. Then the attitude calculation algorithm is implemented. The initial attitude angle is calculated through the corrected geomagnetic data and the accelerometer, and then the angular velocity of the gyroscope is integrated to calculate the direction angle, pitch angle, and roll angle of the current environment to complete the update of the attitude angle and improve Orientation accuracy. The schematic diagram is shown in Figure 2.

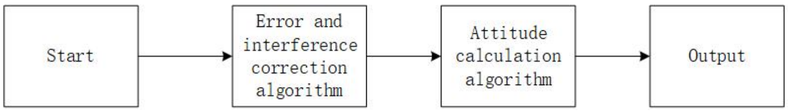


Figure. 2 Principle diagram of geomagnetic orientation

2.3 System combination

Combine the positioning information obtained by the geomagnetic sensor with the strapdown inertial navigation, that is, use the difference between the geomagnetic sensor and the position output by the SINS as the measured value to estimate the error value of the SINS and correct it, so that you can Make corrections to the output of SINS, and its schematic diagram is shown in Figure 3.

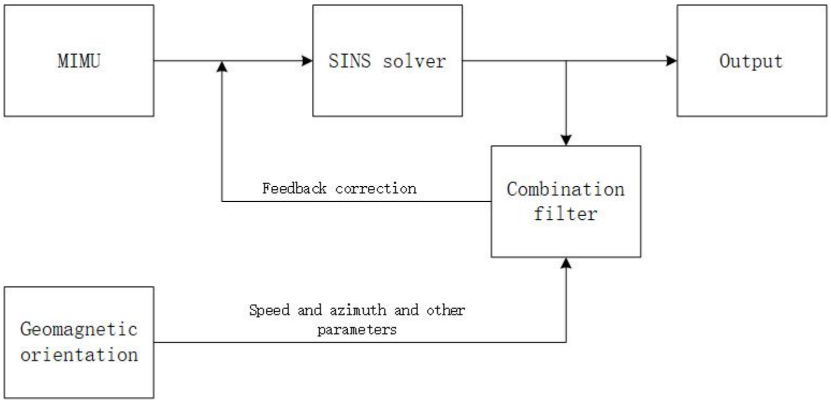


Figure. 3 Schematic diagram of integrated navigation system

The system combination combining these two navigation algorithms has the following advantages:

(1) The system structure is simple, which is more conducive to realization.

(2) Overcome the respective shortcomings of the two systems, thereby obtaining more accurate results.

(3) The two systems work independently, greatly improving the reliability of the overall system.

2.4 Chapter Summary

This chapter mainly introduces the working principle of strapdown inertial navigation system and navigation solution method, and briefly introduces the basic principle of geomagnetic orientation, and finally introduces a system method that combines SINS and geomagnetic orientation, which is helpful for correcting Error caused by time accumulation.

3. Research on Navigation Algorithm Based on Kalman Filter

This chapter first briefly analyzes the error characteristics of the integrated navigation system, and then designs a filtering algorithm based on the error characteristics and combined with Kalman filter, and performs a swing table test to verify the effectiveness of the algorithm.

3.1 System Error Analysis

There are many kinds of system errors of strapdown inertial navigation, mainly inertial device itself error, system installation error, calculation error and errors caused by various interferences [10]. Although these errors have a great influence on the results, some of them Errors can be resolved by adjusting the physical structure of the system, so this article focuses on the remaining errors that have a relatively large impact.

Inertial device error is composed of gyroscope error and accelerometer error, and the gyroscope error mainly includes the following aspects: zero offset, drift, linear error and temperature-induced error. The pre-calibration can solve the fixed error, linear error and temperature-induced error in the zero offset. Only the random drift error needs to be filtered and corrected in the system, and it can be equivalent to an arbitrary constant plus white noise. The error of the accelerometer is similar to that of the gyroscope and can be handled in the same way.

The attitude angle error is caused by the three attitude misalignments between the platform coordinate system and the navigation coordinate system. The attitude angle error can also be derived from the mechanical equation of the strapdown inertial navigation system and compensated for.

3.2 Kalman filtering

Kalman filtering was proposed by the American scholar Kalman to solve the problem of manned spacecraft navigation and control and automatic driving in the case of large disturbances in the moon landing plan. [11] The Kalman filter algorithm is a linear minimum variance estimation and a recursive algorithm for discrete linear filtering. Once the parameter determination and uncertainty model is established, Kalman filter can give the best estimate of the parameter at any time according to the criterion of minimum variance. It can not only estimate and predict the current and past parameter values, but also the future The parameter value at the moment is estimated. Kalman filter has the following two characteristics:

(1) The state space is established: the state is used to represent the signal, and the state equation is listed, which simplifies the estimation method of multi-dimensional signals and non-stationary signals.

(2) Introduce recursive algorithm. The system only needs to analyze the estimated value of the previous moment and the current moment to calculate the current estimated value, without storing the measured value of the past moment, and is suitable for the estimation of the system vector process of white noise excitation.

3.3 The correction process of integrated navigation

Use the state vector obtained after Kalman filtering to correct the system, and the commonly used correction methods include output correction method and feedback correction method. The output correction method refers to directly correcting the output obtained by the system according to the parameter estimation value obtained by filtering, thereby calculating the navigation parameters of the integrated navigation system. The correction process is shown in Figure 4.

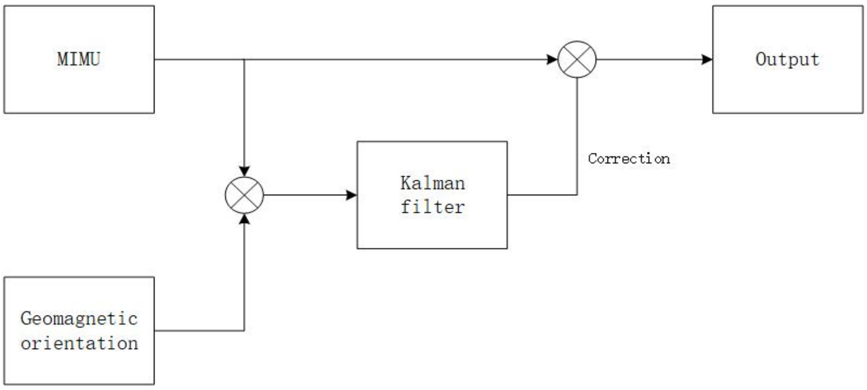


Figure. 4 Schematic diagram of output correction method

The feedback correction method is to feed back the parameter estimates obtained after filtering to the navigation system to correct the error state, and perform subsequent calculations according to the corrected parameters. The correction process is shown in Figure 5.

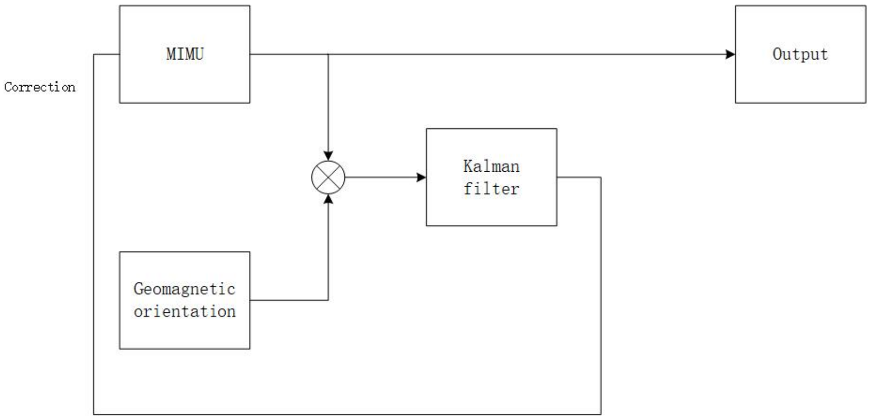


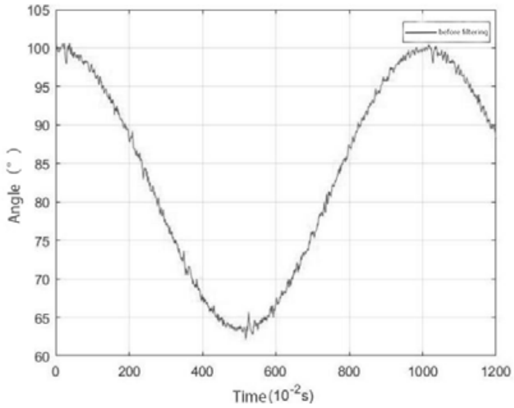
Figure. 5 Schematic diagram of feedback correction method

Compared with the feedback correction method, the output correction method has the advantages of simple structure and independent operation of the system, but the inertial navigation error will accumulate with time, so it cannot solve the error accumulation problem well. However, if the feedback correction method is adopted, the parameters are updated in real time, and the system error will not accumulate over time. Therefore, this paper adopts the feedback correction method to correct the system error.

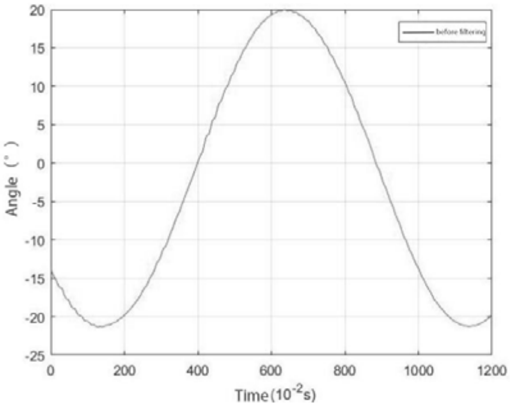
3.4 Swing table test

In order to verify the effectiveness of the integrated navigation system and filtering algorithm, this paper uses a swing table experiment to verify.

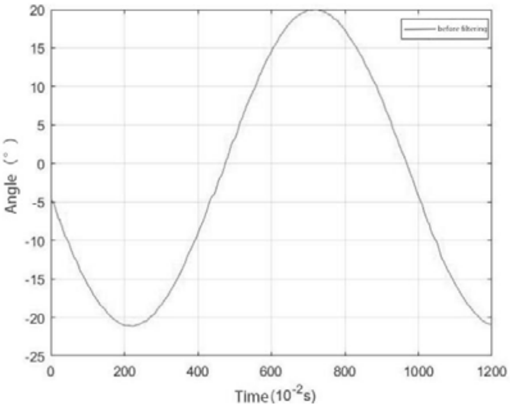
We set the three-axis angles of azimuth, pitch and roll to change periodically, the amplitude is set to 20°, the period is 8 seconds, and the strapdown inertial navigation system performs sinusoidal motion. The experimental results are shown in Figure 6:



(a) Azimuth



(b) pitch

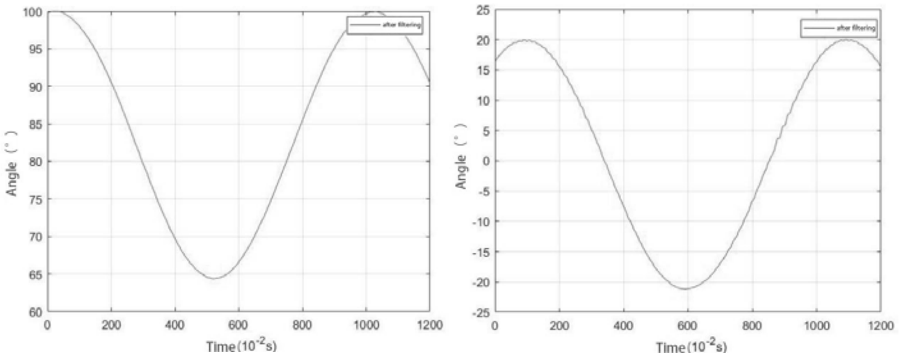


(c) roll

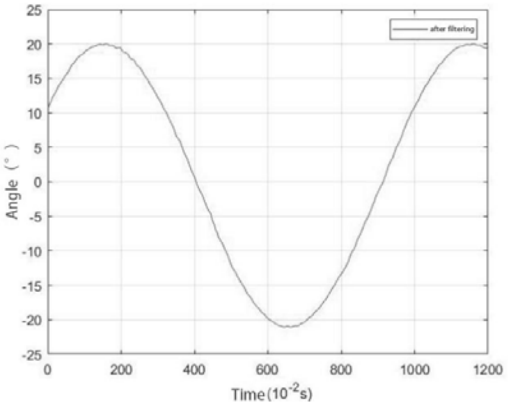
Figure. 6 Test results of the swing table

Due to a certain error of the swing table, the amplitude does not reach the precise 20 degrees, but as long as the amplitude before and after filtering is the same, the error of this part is negligible.

We still assume that the three-axis angle of azimuth, pitch, and roll changes periodically, the amplitude is the same as before, and the period is 8 seconds, but after adding the integrated geomagnetic orientation and filtering and correcting the results. The results are shown in the following figure.



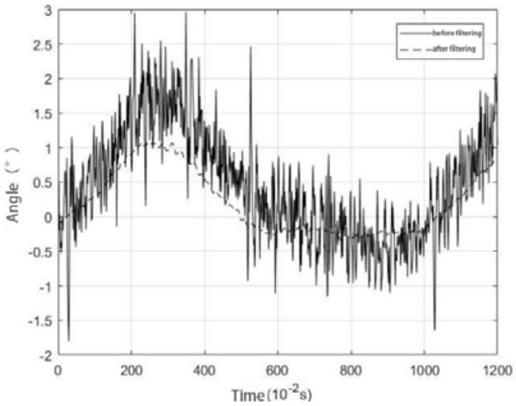
(a) Azimuth (b) pitch



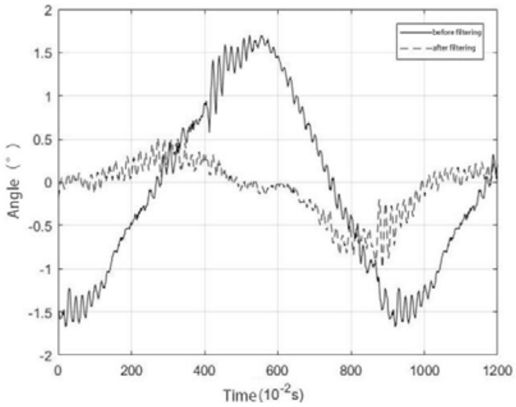
(c) roll

Figure. 7 Test result of integrated navigation swing table

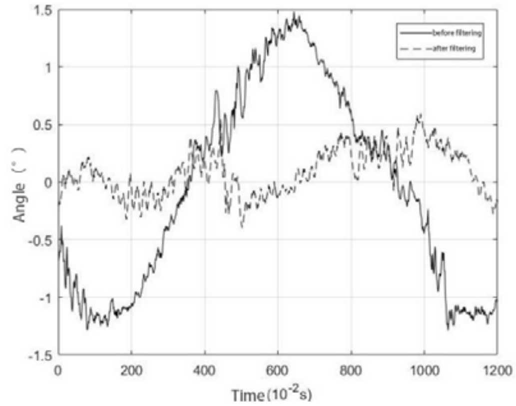
The two results are separately calculated with the sine curve to obtain the error results of the two times.



(a) Azimuth



(b) pitch



(c) roll

Figure. 8 Error comparison chart before and after filtering

It can be seen from the figure that the combined system obviously reduces the error, and the fluctuation of the upper and lower sides is smaller, and the sudden burr phenomenon is eliminated. It can be seen that the combined system of this design has the advantages mentioned above.

4. Conclusion

The development of strapdown inertial navigation system is becoming more and more mature. This paper proposes a design scheme of cheap inertial navigation system for satellite earth station based on MEMS. This article mainly expounds the principles and characteristics of strapdown inertial navigation, geomagnetic orientation, and micro-electromechanical systems. After considering their respective advantages, a filtering algorithm based on Kalman filtering is designed on this basis. This navigation system is combined to form a new combined system. Finally, the feasibility of the system is proved through experiments, which verifies the excellent characteristics and practical value of the system.

After thorough research on MEMS devices, integrated navigation technology, geomagnetic orientation and strapdown inertial navigation system, the structure of the integrated navigation system based on low-cost MEMS devices was determined, and the system’s performance was verified through experiments. The design of the MEMS-based integrated navigation system has significant advantages of small mass and low cost, and at the same time solves the problem of errors due to time accumulation, and has a relatively broad application prospect.

However, due to the limitations of geomagnetic orientation, such as the influence of the magnetic field in the building structure, this system can be combined with the GPS system, and the information from the inertial navigation system and the GPS system can be appropriately combined to better eliminate time The accumulated error brought about can play its own role in more environments.

Although this system is a combination of two navigation systems, it can only feedback and correct the parameter value of SINS, so the data obtained by the geomagnetic sensor cannot be fed back and corrected. In the future, we will consider calibrating the geomagnetic sensor as well.

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