Available online at www.sciencedirect.com
ScienceDirect
Journal of the Franklin Institute 346 (2009) 1021–1037
Journal of The Franklin Institute
www.elsevier.com/locate/jfranklin

New techniques for initial alignment of strapdown inertial navigation system

Shaolin Lü[a,*], Ling Xie[b], Jiabin Chen[b]

[a] *Department of Precision Instruments and Mechanology, Tsinghua University, Beijing 100084, China*
[b] *School of Automation, Beijing Institute of Technology, Beijing 100081, China*

Received 19 September 2008; received in revised form 26 August 2009; accepted 15 September 2009

Abstract

Some new techniques for initial alignment of strapdown inertial navigation system are proposed in this paper. A new solution for the precise azimuth alignment is given in detail. A new prefilter, which consists of an IIR filter and a Kalman filter using hidden Markov model, is designed to attenuate the influence of sensor noise and outer disturbance. Navigation algorithm in alignment is modified to feedback continuously for the closed-loop system. It is shown that the initial estimated variance setting of azimuth angle error can influence the speed of initial alignment significantly. At the beginning of alignment, Kalman filter must make a very conservative guess at the initial value of azimuth angle error to get a high convergent speed of the azimuth angle. It is pointed out that the low signal to noise ratio makes the ordinary setting of the estimated azimuth variance slow down the convergent speed of the azimuth angle. Also is shown that the large azimuth angle error problem can be solved well by our solution. The feasibility of these new techniques is verified by simulation and experiment.

Keywords: Strapdown inertial navigation system; Initial alignment; Kalman filter

1. Introduction

Initial alignment is the first work stage of strapdown inertial navigation system (SINS). The initial azimuth accuracy is one of the main factors which influence the navigation

*Corresponding author.
E-mail address: leo20980@sohu.com (S. Lü).

0016-0032/$32.00 © 2009 The Franklin Institute. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfranklin.2009.09.003

accuracy of SINS. For this reason, initial alignment is always an important issue in navigation field [1–20].

In real environment, the output of inertial measurement unit (IMU) often suffers from large sensor noise. This will slow down the speed of alignment. El-sheimy et al. [18] utilized wavelet de-noising method in IMU alignment. In this paper, a new method is proposed to reduce the influence brought by the mixture of the sensor noise and the outer disturbance. The new prefilter consists of an IIR filter and a Kalman filter using hidden Markov model (HMM). Different from wavelet method which processes the signal in the time–frequency domain, our method works in the frequency and time domain subsequently. Firstly, it filters the high-frequency noise in the frequency domain by the lowpass filter. And then, it works in the time domain by the steady Kalman filter. Wavelet de-noising method has a block processing structure, while the new method possesses of a sequential structure. Thus, the signal can be processed in a realtime way. It does not need to save big-block signal data like wavelet. Benefiting from this merit, the structure of the initial alignment program can be simplified. With this prefilter, the large noise problem of SINS on a vehicle with the engine on can be solved well and easily.

Navigation algorithm has been studied very well [21,22]. Here, it will be modified for the closed-loop Kalman filter in alignment. With it, SINS can work like the gimbal system in the alignment stage. Moreover, since the modification is very slight, it will not bring too much computation burden. When this navigation algorithm is implemented, the error model needs to be modified accordingly. Error models of SINS have been lucubrated [9,23]. In this paper, only the $\psi-$angle error model is considered and modified.

Using the conventional Kalman filter design method, the precise azimuth alignment suffers a low convergent speed of the azimuth angle. Observability analysis of $\psi-$angle error model with velocity measurement was made by Bar-Itzhack et al. [9] and Jiang [12]. It is widely accepted that since the azimuth angle error is not completely observable it will cost Kalman filter a very long time to estimate the azimuth angle error.

In this paper, it will be pointed out that in alignment the estimated variance of the azimuth error should be initialized as a large value. If Kalman filter works with a proper setting of this variance, the azimuth angle error will decrease soon. Also it will be shown that the low signal to noise ratio of gyroscope makes this phenomenon happen. The reason why the azimuth angle gets convergent very slow with an ordinary variance setting is not that the system is not completely observable. The reason is that the earth angular rate is too slow and the sensor noise is too large.

Generally, the first stage of SINS initial alignment is coarse alignment [15,17]. Coarse alignment is a very short procedure which purpose is to provide a good condition for fine alignment. However, in practice the accuracy provided by coarse alignment may be very low. Under this condition, the precise alignment may be accomplished with a large azimuth error. This problem is called the large azimuth error problem. To solve this problem, the modified $\psi-$angle model [11,24] is proposed. Nonlinear filtering is used to accomplish the initial alignment with a large azimuth error [16]. Here, it will be shown that using our solution this problem can be solved well with the $\psi-$angle model by a closed-loop Kalman filter. The modified $\psi-$angle model or nonlinear model is not necessary. If the azimuth angle error is large, for example 180°, the correction speed of the angle error can be accelerated by the large azimuth variance to make the angle error decrease quickly, which makes the $\psi-$angle model proper for initial alignment.