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Mooring alignment for marine SINS using the digital filter

Feng Sun, Wei Sun *

College of Automation, Harbin Engineering University, Harbin, Heilongjiang Province, China

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ABSTRACT

Strapdown inertial navigation system (SINS) is presently used in several applications related to aerospace system and marine navigation. The accurate initial attitude is essential to ensure the precise determination of the position and attitude of the moving platform, which is usually calculated using initial alignment. When the vehicle is moored, the SINS inevitably experience disturbing motion. The method of ground coarse alignment, which is based on the assumption that SINS is on a stationary carrier with limited vibration, therefore cannot be used to perform the SINS mooring alignment. In this paper, a novel method processing the gyro and accelerometer measurements with infinite impulse response (IIR) digital low-pass filter to remove the high frequency noise is investigated for marine mooring alignment. Its algorithmic principle is described in details. The results obtained from both simulation and mooring experiment show that the attitude determined by this novel method can meet the accurate alignment.

1. Introduction

The navigation parameters (position, velocity, and attitude) are calculated in navigation frame through the transformation from the body frame to the navigation frame using the attitude matrix [1]. The relationship between the navigation frame and the body frame is realized by continuously updating this attitude matrix. To limit the errors in the derived navigation parameters, it is very important to determine the initial value of such matrix with high accuracy [2–4]. The process of computing the initial value of attitude matrix, is known as the alignment of the SINS. Normally, the traditional alignment process consists of two steps – coarse and fine alignment [5]. The purpose of coarse alignment is to calculate the initial attitude angles rapidly. The fine alignment, then, is used to refine the coarse alignment.

In static ground alignment, the system attitude can be determined directly by using the gravity and earth rate signals in the navigation frame and the measurements obtained by using accelerometers and gyros, given that the SINS is on a stationary base with limited vibration [6,7]. However, the swing of marine will be caused by the wind wave. During the alignment process of SINS, gyros are employed to monitor the components of the earth rotation rate along their sensitive axes to determine the initial attitude of the moving platform [8]. The angular rate error which is decided by the wind wave is much larger than earth rate. So, the signal-to-noise ratio of gyro's output is poor, and the frequency band of angular rate error is wide [9]. It is impossible to get the Earth rate from gyros. Therefore, a feasible alignment solution for marine SINS would avoid the direct use of the Earth rate and gravity obtained by using gyros and accelerometers.

In order to resolve the alignment when the marine is on swing, many methods have been developed and analyzed for the vehicle's swing and vibration. Giovanni and Levinson [10], Wan [11], Zhang [12], Gaiffe and Napolitano [13,14] etc., have presented the different algorithms. Considering the earth rate is constant in body inertial frame, we can get the north from the projection of the gravity in the inertial frame defines a cone whose main axis is the rotational axis of the Earth (see Fig. 1). In this paper, a novel method is introduced to use the gravity and earth rate

* Corresponding author.
E-mail address: sunwei-3775235@163.com (W. Sun).

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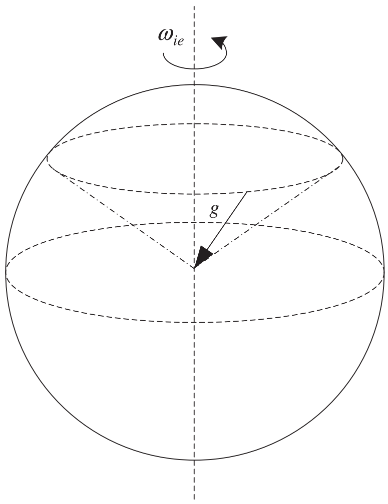

Fig. 1. The coning motion of gravity in inertial frame.

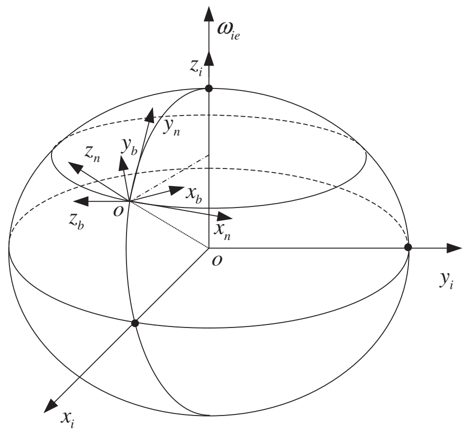

Fig. 2. The frames definition.

signals in the navigation frame and the body inertial frame to establish the initial attitude matrix.

This paper is organized as follows. The coordinate frames used in this paper are defined in Section 2. In Section 3, the algorithmic principle for the analytic alignment in inertial frame is presented. The IIR low-pass digital filter is designed in Section 4. The results from simulation and mooring experiment are illustrated in Section 5. Finally, the conclusion is presented in Section 6.

2. Frame definitions

The frames which are used in this paper are defined as follows:

(1) The i frame is inertial frame which is stabilize in the inertial space. In this article, it is formed by fixing the earth frame at the beginning of the coarse alignment in the inertial space.
(2) The b frame is the vehicle body frame. The x_b axis is parallel to the ship lateral axis and points to the right. The y_b axis is parallel to the ship longitudinal axis and points to the forward. The z_b axis is parallel to the ship vertical axis and points upward.
(3) The n frame is the navigation frame. The local level frame is usually considered as the n frame in SINS.
(4) The i_{b0} frame is the body inertial frame [5]. It is formed by fixing the b frame at the beginning of the initial alignment in the inertial space.

The above mentioned frames of the initial alignment are shown in Fig. 2.

3. Analytic alignment of inertial systems

The navigation parameters are provided in navigation frame through the transformation from body frame to navigation frame using the attitude matrix T_b^n. To limit the errors in the updating this attitude matrix, it is very important to decide the initial value of attitude matrix with high accuracy. In order to improve the accuracy of alignment, the body inertial frame is introduced into the analytic alignment. So, the attitude matrix, which relates the body frame to the navigation frame, could be described as follows:

$$T_b^n = T_{i_{b0}}^n T_b^{i_{b0}} \tag{1}$$

Eq. (1) shows the progress of alignment which can be divided into two phases. Where, $T_b^{i_{b0}}$ is the rotation matrix of the body frame relative to the reference frame and can be calculated using the gyro output. The updating algorithm for $T_b^{i_{b0}}$ can be constructed as follows using the product chain rule:

$$\dot{T}_b^{i_{b0}} = T_b^{i_{b0}}[\omega_{ib}^b \times] \tag{2}$$

The key operation of the attitude algorithm is to properly update the quaternion. The quaternion update is obtained by the following quaternion differential equation:

$$\dot{q} = \frac{1}{2} q \omega_{ib}^b \tag{3}$$

where q denotes the attitude quaternion, and ω_{ib}^b denotes the angular rate vector of the body frame relative to the inertial frame. Eq. (3) can be expressed in the form:

$$\dot{x} = f(x) \tag{4}$$

where:

$$x = [\,q_0 \quad q_1 \quad q_2 \quad q_3\,]^T$$

Aiming at the condition, in which the outputs of inertial sensors are the angular rate and the specific force acceleration, utilizing the fourth order Runge-Kutta to solve the above differential equation and to achieve the attitude updating. The solving process can be represented as [15]:

$$x(t+h) = x(t) + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{5}$$

where: