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Online estimation and compensation method of installation error for rotating-modulated north seeker

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ABSTRACT

The installation error existed in rotating-modulated north seeker will result in a large output azimuth error. To solve this problem, an online estimation and compensation method of installation error for rotating-modulated north seeker based on fiber optic gyroscope (FOG) is proposed in this paper. Simulations are performed to confirm the efficiency of the proposed method. As can be seen from our simulation results, the proposed online installation error compensation method can improve the accuracy of north seeker significantly.

1. Introduction

Fiber optic gyroscope (FOG) has been used as a rotation sensor in north seeker due to its merits in high precision, small size, light weight, and large dynamic range [1,2]. Generally, north seeker schemes include static and dynamic schemes. In static scheme, FOG is mounted on rotating platform and its sensitivity axis is parallel to rotation platform plane. Controlled by rotation platform, the FOG rotates to 2, 3 or 4 specified positions. Then the azimuth angle can then be calculated from the output of FOG at different positions. As shown in [3], FOG drift will degrade the performance of static scheme north seeker. To solve this problem, rotating-modulated method is proposed in [1–6]. It can be deemed as a dynamic north seeker scheme. During the north seeking process, the inertial measurement unit (IMU) rotates around the turntable's vertical center axis with a constant speed. The carrier's azimuth angle can then be calculated from the output signal of IMU. Comparing with traditional static north seeking scheme, the output signal of FOG is modulated by the rotation of turntable, and gyro drift can be suppressed. The precision of north seeker can then be improved. The principle of dynamic north seeking is discussed in detail in [2]. A dynamic scheme north finder using a fiber optic gyroscope is proposed in [3].

In the manufacture of north seeker, the installation error is defined as Euler angles of the transform matrix between IMU frame and turntable frame, which can be compensated in the calibration of the north seeker. However, in practical applications of north seeker, with the change of environmental factors such as humidity, temperature, and vibration, the mechanical connection between IMU and turntable will deform, which will result in the change of installation error angle, and the performance of north seeker will degrade. To solve this problem, an online estimation and compensation method of installation error for rotating-modulated north seeker composed by a uniaxial FOG and an accelerometer is proposed in this paper, and simulation is performed to show the efficiency of the proposed method. As can be seen from our analysis of simulation results, the proposed installation error compensation method can improve the accuracy of north seeker.

This paper is organized as follows: the output model of IMU in rotating-modulated north seeker composed by a uniaxial FOG and an accelerometer is introduced in Section 2. Installation error online estimation and compensation method is proposed in Section 3. Simulation is performed in Section 4. Finally, conclusion is given in Section 5.

2. Output model of IMU in rotating-modulated north seeker

This section describes the output model of rotating-modulated north seeker.

Nomenclature:

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i-frame: the inertial coordinate system. Its origin is at the center of the Earth and axes are non-rotating with respect to the fixed stars, defined by the axes ox_i, oy_i, oz_i, with oz_i coincident with the Earth's polar axis (which is assumed to be invariant in direction).

n-frame: the geographic coordinate system. Its origin is at the center of the turntable plane and axes ox_n, oy_n, oz_n are aligned with the directions of east, north and the local vertical (up), respectively.

b-frame: the body-fixed coordinate system. Its origin coincides with the *n*-frame's and ox_b, oy_b are horizontal axes in the direction of carrier's lateral and longitudinal vectors, respectively. The axis oz_b is to make a right-handed orthogonal coordinate system.

b_i-frame: the platform coordinate system when turntable rotates. At the beginning, the b_i-frame coincides with the *b*-frame and when turntable rotates, axes ox_{b_i}, oy_{b_i} rotate around the turntable's vertical center axis.

g-frame: the gyro coordinate system. Its origin coincides with the *n*-frame's too. If we assume the gyro and accelerometer are installed on *y*-axis, then oy_g is parallel to the sensitive axis of the gyro, and ox_g is on the gyro fiber coil plane.

H, θ, γ: the body's azimuth, pitch and roll, respectively.

η_x, η_y, η_z: the installation error angle defined as the Euler angle between the b_i-frame and the *g*-frame.

Ω: the rotation angular velocity of turntable which is a constant.

α_i: the angle of the *i*th position of gyro when the turntable is rotating. $\alpha_i = \Omega t_i$, where t_i is the time that turntable rotates from the initial position to the *i*th position.

Each frame is an orthogonal, right-handed, coordinate frame.

The conversation relationships between *n*-frame and *b*-frame, *b*-frame and b_i-frame are shown in Fig. 1(a) and (b), respectively.

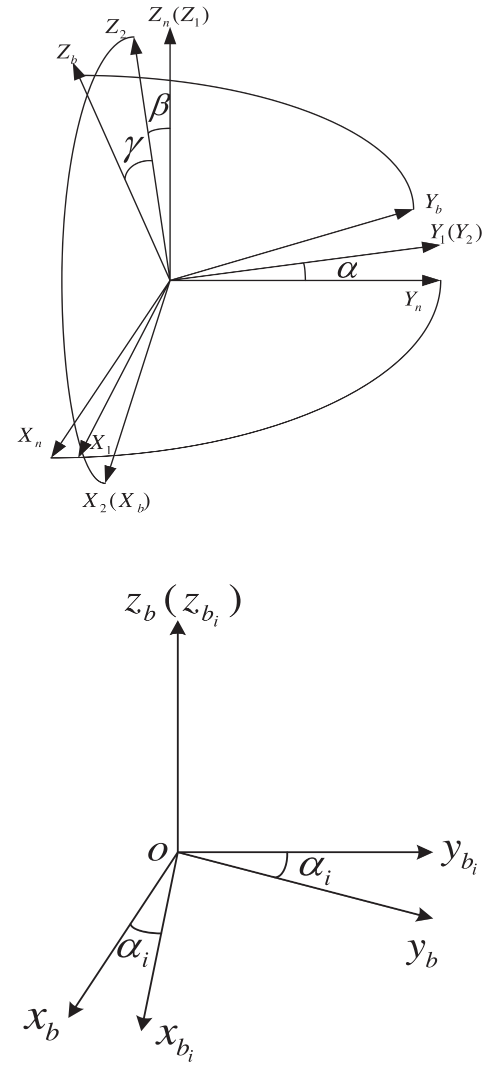

Fig. 1. (a) The transform diagram from *n*-frame to the *b*-frame. (b) The transform diagram from *b*-frame to the b_i-frame.

2.1. Transform relationships between coordinate systems

Direction cosine matrix $\mathbf{C}_n^b$ between the *n*-frame and the *b*-frame is as follows:

$$\mathbf{C}_n^b = \begin{bmatrix} \cos\gamma\cos H - \sin\theta\sin\gamma\sin H & \cos\gamma\sin H + \sin\theta\sin\gamma\cos H & -\cos\theta\sin\gamma \\ -\cos\theta\sin H & \cos\theta\cos H & \sin\theta \\ \sin\gamma\cos H + \sin\theta\cos\gamma\sin H & \sin\gamma\sin H - \sin\theta\cos\gamma\cos H & \cos\theta\cos\gamma \end{bmatrix} \tag{1}$$

Direction cosine matrix $\mathbf{C}_b^{b_i}$ between the *b*-frame and the b_i-frame is as follows:

$$\mathbf{C}_b^{b_i} = \begin{bmatrix} \cos\alpha_i & \sin\alpha_i & 0 \\ -\sin\alpha_i & \cos\alpha_i & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

Assuming that the installation error angles between the b_i-frame and the *g*-frame are small, the direction cosine matrix $\mathbf{C}_{b_i}^g$ can be approximated as follows [7]:

$$\mathbf{C}_{b_i}^g = \begin{bmatrix} 1 & \eta_z & -\eta_y \\ -\eta_z & 1 & \eta_x \\ \eta_y & -\eta_x & 1 \end{bmatrix} \tag{3}$$

Note that the north seeking system in this paper just uses one gyro and one accelerometer as abovementioned, so the installation error angle which should be compensated is η_z and η_x, η_y are just used for mathematical analysis.

2.2. The output model of IMU in north seeker with installation error

2.2.1. The output model of gyro with installation error

Considering the existence of gyro's installation error, the angular velocity of *g*-frame with respect to *i*-frame projected in *g*-frame include two parts: the velocity of earth rotation and the velocity of turntable's rotation, as shown below:

$$\boldsymbol{\omega}^g = \mathbf{C}_{b_i}^g \left(\mathbf{C}_b^{b_i}\mathbf{C}_n^b \cdot \boldsymbol{\omega}_{ie}^n + \begin{bmatrix} 0 \\ 0 \\ \Omega \end{bmatrix} \right) = \mathbf{C}_{b_i}^g \left(\mathbf{C}_b^{b_i}\mathbf{C}_n^b \cdot \begin{bmatrix} 0 \\ \omega_N \\ \omega_H \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \Omega \end{bmatrix} \right) \tag{4}$$