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An inertial measurement method of ship deformation based on IMM filtering

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ABSTRACT

Matching filtering algorithm based on inertial measurement unit is the development trend of deformation of ship hull. Kalman filter requires that the system model parameters are known accurately, however the parameters of the actual ship hull deformation model are unknown or uncertain. According to the above problem, this paper introduces interacting multiple models (IMM) Kalman filtering method based on the "velocity plus angular velocity" model matching. The estimated residuals of each model are used to calculate the probability of the corresponding model. Finally, simulation results show fast convergence, good stability and high accuracy of the proposed algorithm. Then, we use the Monte Carlo simulation. The results show that the IMM can increase 5%–10% accuracy than the Kalman filter. The IMM algorithm can improve the estimation accuracy of the deformation angle and the environmental adaptability compared with the traditional Kalman filter.

1. Introduction

With the progress of science and technology, modern ships and shipboard equipment are in rapid development in the direction of high precision and high automation. To ensure the normal operation of shipboard equipment, they need to establish an unified standard of space attitude. However, the ship is not an absolute rigid body, the accuracy of the space attitude datum is severely restricted due to the deformation of the hull while at sea [1].

With the development of computer technology in twentieth century, the finite element analysis method began to be used to calculate the deformation of the hull under various external forces [2]. Based on the establishment of the whole ship finite element model, the computer is used to calculate the wave force on the hull model, and finally obtains the deformation of the ship. However, this method has a large amount of computation, and can not be estimated in real time.

Since then, with the new high precision sensors appear constantly, a large number of new methods to measure the hull deformation also came into being [3]. In the 1960s the United States proposed the polarized energy measurement method for measuring the hull transverse twist angle. Since 1980s, foreign counties have used the inertial measurement unit measuring the deformation angle to eliminate the error. In the 1990s, with global coverage of GPS satellite, GPS measurement method has emerged with high accuracy, but the GPS system can not work normally when the GPS signal is disturbed. The inertial measurement method can update heading, attitude, angular rate information real time. It does not rely on outside equipment, and can operate independently according to the parameters set.

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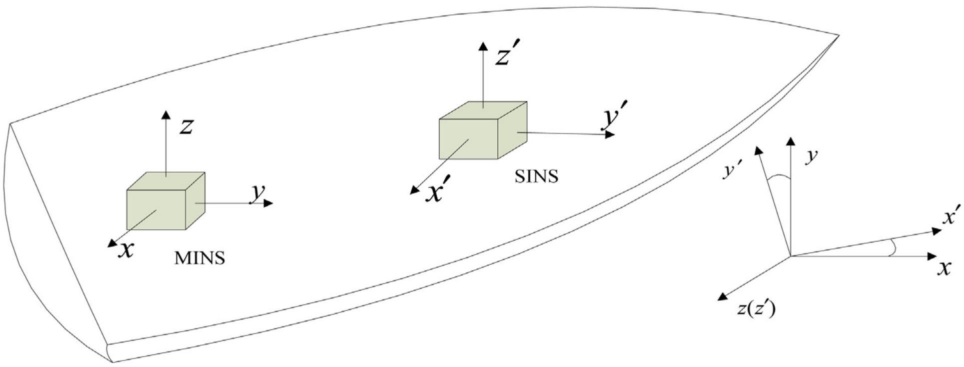

Fig. 1. Schematic diagram of the principle of measuring the deformation of the ship hull.

In recent years, many countries have begun to research the hull deformation. The Russia carry out research in this area since the end of 1980s [4,5]. The United States military plane used strain compensation method [6]. Some achievements have been also made in the ship deformation in our country. National Defense University of Science and Technology installed inertial measurement unit in fighting positions [7], the results show that the method only in moderate sea state is effective. Qin Shiqiao, Zheng Jiaxing and other scholars have proposed a new method of deformation measurement based on the attitude matching [8], which can ignore the initial attitude alignment. At the same time,the team proposed to improve the static deformation angle model [9,10]. But these methods don't take the actual situation into account that the structure of the model is not determined, or the model parameters change.

IMM estimation is a kind of adaptive estimation method, which is very effective for solving the structure and parameter uncertainty or change in the system. At present, the IMM estimation is mainly used to solve the accurate estimation of target state in the process of target tracking. Dr. X. R. Li proposed variable structure multiple model thought in 1992, and gave the concrete realization algorithm of variable structure multiple model [11].

In this paper, IMM algorithm is used to estimate the hull deformation angle when the deformation angle model is uncertain or the parameters are uncertain.

2. Hull model

The Fig. 1 shows that the position relation between master INS and the slave INS on ship hull. In this paper, the hull deformation model is established based on "velocity + angular rate" matching, and the system state vector is selected as follows.

$$\boldsymbol{X} = [\,\boldsymbol{\delta V} \quad \boldsymbol{\varphi} \quad \nabla \quad \boldsymbol{\varepsilon} \quad \boldsymbol{\xi} \quad \boldsymbol{\theta} \quad \dot{\boldsymbol{\theta}}\,]^{\boldsymbol{T}}$$

In the formula, $\delta\mathbf{V}$ denotes INS velocity error, φ denotes INS attitude error, ∇ and $\boldsymbol{\varepsilon}$ denote accelerometer bias and gyroscope drift, $\boldsymbol{\xi}$ denotes installation error angle between the master INS and the slave INS, $\boldsymbol{\theta}$ denotes deflection angle, $\dot{\boldsymbol{\theta}}$ denotes the angular velocity of deflection angle.

The corresponding error equations are as follows

$$\delta\dot{V} = -\varphi^n \times f^n + \delta V^n \times (2\omega_{ie}^n + \omega_{en}^n) + V^n \times (2\delta\omega_{ie}^n + \delta\omega_{en}^n) + \nabla^n \tag{1}$$

$$\dot{\varphi} = \varphi \times \omega_{in}^n + \delta\omega_{in}^n - C_b^n \varepsilon^b \tag{2}$$

Accelerometer bias ∇ and gyroscope drift $\boldsymbol{\varepsilon}$ are the main error sources of the INS. According to the characteristics of gyro drift, it usually consists of random constant drift $\boldsymbol{\varepsilon_0}$ and slow drift $\boldsymbol{\varepsilon_r}$. The random constant drift can be regarded as a random constant, and also can be expressed by the following formula.

$$\boldsymbol{\varepsilon_0} = \mathbf{0} \tag{3}$$

The slow drift $\boldsymbol{\varepsilon_r}$ is a first-order Markov process driven by white noise $\boldsymbol{w_r}$, and can be described by the following model.

$$\dot{\boldsymbol{\varepsilon}}_{\boldsymbol{r}} = -\frac{1}{\tau_r}\boldsymbol{\varepsilon_r} + w_r \tag{4}$$

Because the correlation time is very long, the slow drift can be deemed as a constant, ie.

$$\dot{\boldsymbol{\varepsilon}}_{\mathbf{r}} = \mathbf{0} \tag{5}$$

In summary, gyro drift can be expressed as follows.

$$\dot{\boldsymbol{\varepsilon}}_{\mathbf{b}} = \dot{\boldsymbol{\varepsilon}}_0 + \dot{\boldsymbol{\varepsilon}}_r = \mathbf{0} \tag{6}$$