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Attitude measurement system based on micro-silicon accelerometer array

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Abstract

This paper analyzes theoretically the strap-down inertia measurement system with nine micro-silicon accelerometers array and its attitude algorithm model. The error sources and characteristics in this measurement system are also analyzed. The algorithm model is validated by simulation experiment on the ground and the experimental results are presented. Finally, experimental errors are modified and compensated to improve algorithm precision based on micro-silicon accelerometer array.

1. Introduction

The strap-down inertial measurement system with micro-silicon accelerometer array is mainly used to measure accurately attitude parameters of the flying object. Compared with the strap-down inertial measurement system composed with gyros and accelerometers, its main advantages are that it reduces cost and can resist high over-loading.

The inertial measurement system is composed with nine micro-silicon accelerometers array. It will be installed to the flying object and flies with the flying object together. So this system can measure real-time acceleration values in their corresponding direction. According to these acceleration values, their corresponding attitudes can be obtained by attitude algorithm model. These data will provide necessary reference for inertial navigation.

The paper mainly introduces the strap-down inertial measurement system and its attitude algorithm model based on the micro-silicon accelerometers array, and analyzes the error sources and characteristics in this measurement system. The authors present the results of simulating experiment on the ground. In the end in order to improve measurement precision, the researchers modify experimental errors through different methods.

2. Inertial measurement system and attitude algorithm model

In theory six accelerometers are needed to describe the rigid body's movement at least. Only when these six accelerometers' positions and directions are arranged reasonably can the movement of the rigid movement be described

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accurately. However, in order to improve measurement precision it needs to compensate the effect of the intersection item in the angular velocity in algorithm of the attitude parameters [1].

The measurement system with nine micro-silicon accelerometers uses more accelerometers, making it possible to reduce the redundancy of the accelerometer signals caused by intersection item from the angle velocity. Therefore to a certain degree it improves measurement precision. The installation model is shown in Fig. 1.

The inertia measurement system consists of nine micro-silicon accelerometers array, signal-conditioning device, signal acquisition device, signal memorizing device and central controlling device. When the flying object is high over-loading, it can still record and store real-time acceleration values during flying course. After the flying object is recovered, the attitude parameters can be solved ex post by computer. The measurement unit is shown as Fig. 2.

The equation of the specific force measured with the accelerometer that is installed at any point of the flying object is as follows [2–4]:

$$\bar{f}^b = \dot{\overline{V}}{}^b_{en} + \dot{\bar{\omega}}^b_{nb} \times \overline{L}^b + \bar{\omega}^b_{nb} \times (\bar{\omega}^b_{nb} \times \overline{L}^b) + (2\bar{\omega}^b_{ie} + \bar{\omega}^b_{en}) \times (\overline{V}^b_{en} + \bar{\omega}^b_{en} \times \overline{L}^b) + \bar{g}^b + \overline{\nabla}^b \tag{1}$$

The flying parameters at any time may be gotten by specific force equation from the combination of accelerometers. Because this strap-down inertial measurement system replaces the function of gyros with the accelerometers, the calculating precision for the angular acceleration and velocity at any time is very important. The calculating formulas are showed as follows:

$$\begin{cases} \dot{\omega}^b_z = \frac{1}{2}\left[(f_b - f_d)/(L_b - L_d) + A^b_x/L_f - f_f/L_f\right] + \frac{1}{2}[\varepsilon_{YX} - \varepsilon_{XY}] \\ \dot{\omega}^b_x = \frac{1}{2}\left[f_e/L_e - f_g/L_g + A^b_y/L_g - A^b_z/L_e\right] + \frac{1}{2}[\varepsilon_{ZY} - \varepsilon_{YZ}] \\ \dot{\omega}^b_y = \frac{1}{2}[(f_h - f_i)/(L_h - L_i) - (f_a - f_c)/(L_a - L_c)] + \frac{1}{2}[\varepsilon_{XZ} - \varepsilon_{ZX}] \end{cases} \tag{2}$$

$$\begin{cases} \omega^b_{z1}(k) = \omega^b_z(k-1) + \int_{(k-1)T}^{kT} \dot{\omega}^b_z(t)\,\mathrm{d}t \\ \omega^b_{x1}(k) = \omega^b_x(k-1) + \int_{(k-1)T}^{kT} \dot{\omega}^b_x(t)\,\mathrm{d}t \\ \omega^b_{y1}(k) = \omega^b_y(k-1) + \int_{(k-1)T}^{kT} \dot{\omega}^b_y(t)\,\mathrm{d}t \end{cases} \tag{3}$$

$$\begin{cases} \omega^b_z\omega^b_x = \frac{1}{2}[(f_h - f_i)/(L_h - L_i) + (f_a - f_c)/(L_a - L_c)] - \frac{1}{2}(\varepsilon_{ZX} + \varepsilon_{XZ}) \\ \omega^b_z\omega^b_y = \frac{1}{2}[f_e/L_e + f_g/L_g - A_z/L_e - A_y/L_g] - \frac{1}{2}(\varepsilon_{ZY} + \varepsilon_{YZ}) \\ \omega^b_x\omega^b_y = \frac{1}{2}[(f_b - f_d)/(L_b - L_d) - A_x/L_f + f_f/L_f] - \frac{1}{2}(\varepsilon_{XY} + \varepsilon_{YX}) \end{cases} \tag{4}$$

The rotation vector algorithm is used to calculate the attitude angle, and here we describe the tri-subsample and quadruple-subsample of the algorithm. The rotation vector can be denoted as Φ. The tri-subsample algorithm makes three

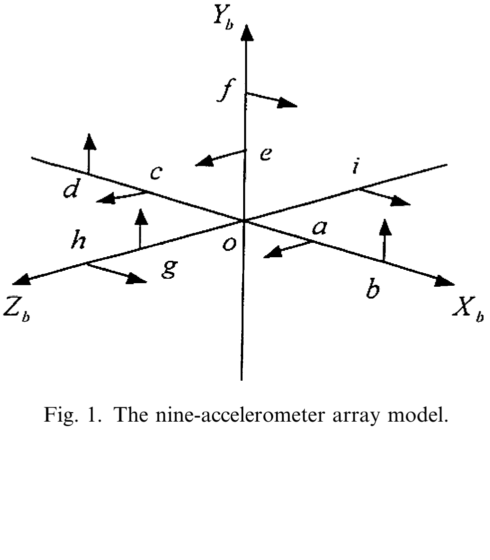

Fig. 1. The nine-accelerometer array model.