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Gyroscope Free Strapdown Inertial Measurement Unit by Six Linear Accelerometers

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A six-accelerometer configuration is presented to compute the rotational and translational acceleration of a rigid body. This theoretical minimum accelerometer configuration has as stable a mechanization equation as that of recent results of nine-accelerometer schemes. Associated equations that can be used to work with the accelerometer location and orientation errors are also derived. For navigation application, the novel design can be integrated with other sensors of complementary characteristics to enhance the performance.

Introduction

MOST current inertial navigation systems use linear accelerometers to sense linear accelerations and gyroscopes to sense angular velocity or angular position. However, it is possible to determine the kinematics of a rigid body by using only linear accelerometers. This viewpoint has been vigorously studied for over 20 years in connection with a number of diverse disciplines, such as inertial navigation, experimental modal analysis, and biomechanical research.[1-3] In theory, a minimum of six linear accelerometers are required for a complete description of a rigid body motion. However six-accelerometer schemes were unsuccessful in the past. Recent results show that workable schemes for a stable solution need nine accelerometers.[2-5] The key to the solution of this problem is the choice of location and orientation of these accelerometers.

We present a theoretical minimum workable six-accelerometer configuration. Our design has one accelerometer at the center of each face of a cube. The sensing axis of each accelerometer is along the respective cube face diagonal, in such a way that these diagonals form a regular tetrahedron. The rotational acceleration of the body can be computed from six acceleration field measurements. Direct integration of $\dot{\omega}$ with given initial condition $\omega(0)$ yields angular velocity ω. The translational acceleration at the center of the configuration is computed from the measurements and the knowledge of angular velocity.

Basic Principle

The accelerometer is a precision instrument designed to measure a component of the vector quantity called specific force f. It is defined by the equation

$$f = a - g \tag{1}$$

where a is inertial acceleration and g is gravitational attraction per unit mass. In navigation computation, we must calculate g and use $f + g$ to obtain the inertial acceleration a of a moving vehicle. For simplicity and without loss of generality, we will neglect the gravitation effect in the following discussion.

In describing the motion of a vehicular system, consider an inertial frame (I frame) and a rotating moving frame (b frame) as shown in Fig. 1. The acceleration of point P is given by

$$a = (\ddot{R})_I + (\ddot{r})_b + \dot{\omega} \times r + 2\omega \times (\dot{r})_b + \omega \times (\omega \times r) \tag{2}$$

where $(\ddot{r})_b$ is the acceleration of point P relative to body frame. $(\ddot{R})_I$ is acceleration of O_2 relative to O_1. The term $2\omega \times (\dot{r})_b$ is known as the Coriolis acceleration, $\omega \times (\omega \times r)$ represents a centripetal acceleration, and $\dot{\omega} \times r$ is the tangential acceleration owing to angular acceleration of the rotating frame.

If P is fixed in the b frame, the terms $(\dot{r}_i)_b$ and $(\ddot{r}_i)_b$ vanish. Thus a body rigidly mounted accelerometer at location r_i with sensing direction $\hat{\theta}_i$ would produce output of A_i

$$A_i = \left[(\ddot{R})_I + \dot{\Omega} r_i + \Omega\Omega r_i\right] \cdot \hat{\theta}_i \tag{3}$$

where

$$\Omega = \begin{bmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix} \tag{4}$$

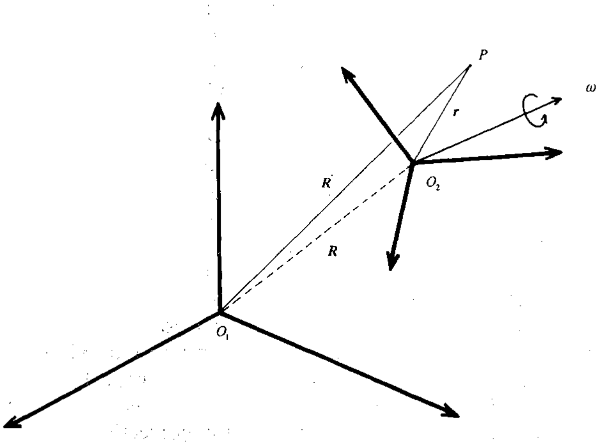

Fig. 1 Geometry of moving frame (b) and inertial frame (I).

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