Key Engineering Materials *Online: 2013-07-15*
ISSN: 1662-9795, Vols. 562-565, pp 549-552
doi:10.4028/www.scientific.net/KEM.562-565.549
© 2013 Trans Tech Publications Ltd, All Rights Reserved

Research on MEMS Based Real-time Measurement System for Motion Information of the Vehicle

Zhao Fei[1, a], Zhou Zhaoying [2, b], Xiong Jijun [3, c], Zhao Jifeng[4, d], Liu Jiajin[5, e]

[1,3]National Key Laboratory for Electronic Measurement Technology (North University of China), Taiyuan, China

[2]State Key Laboratory of Precision Measurement Technology and Instruments (Tsinghua University), Beijing, China

[4]Shanxi Provincial Economic Construction Investment Corporation, Taiyuan, China

[5]China University of Mining & Technology (Beijing), Beijing, China

[a]zhaofeimems@foxmail.com, [b]zhouzy@mail.tsinghua.edu.cn, [c]xongjijun@nuc.edu.cn, [d]jjtzjf@163.com, [e] liu89967@126.com,

Keywords: Micro Electromechanical Sensors Data Recording System FLASH Memory

Abstract. This paper presents a new type of measurement and recording device for motion information of the vehicle, and proposes a method of the multi-sensor data fusion. The system utilized a kind of MEMS-Based sensors, such as the angular rate gyros, the accelerometer, the magnetometer, the absolute pressure sensor, the differential pressure sensor and the GPS module. It is for measuring vehicle`s angular rate movement, acceleration, magnetic heading, altitude, air speed, latitude and longitude coordinates respectively. The entire system is integrated in a small circuit board with a small size, low power and high-stability characteristics.

Introduction

With the rapid development of small unmanned systems, the applications, such as MAV, USV and so on, has broad prospects in the fields of civil and military. As the size of the system continues to shrink, the sensors which were used in the past system have been unable to meet the current requirements.

Since the technology of MEMS (Micro Electromechanical System) is becoming increasingly matured, the problem mentioned above has already been solved. However, in the regular measuring device, the attitude of the vehicle is only achieved from the integration of three-axis gyro data. However, because of the serious drift of the MEMS devices, there will be a big error existing in the attitude of the vehicle gotten in this way. And the three-axis MEMS sensor group still have the error of quadrature [1]. If the accuracy is out of specification, the recorded data of the system cannot reflect the dynamic process of the vehicle exactly.

Therefore, the quadrature error compensation and the multi-sensor data fusion are very significant to the accuracy of the measurement system. So this article will discuss these issues mentioned above mainly.

The quadrature error compensation

As to the three-axis sensor of the measurement and recording system, it is a combination of three single-axis sensors. Three-axis coordinate of the sensor should be the orthogonal coordinate ($oXYZ$). However, owing to the engineering installation, there will be errors between the actual coordinate of the three-axis and the ideal one [2].

When in an ideal condition, the output data of three-axis sensor group is: $W_1 = [w_x \quad w_y \quad w_z]^T$. Because of the quadrature error, the actual data $W_2 = [w_x` \quad w_y` \quad w_z`]^T$ is different from the ideal value. Then the following relationship between the two sets of the data can be found:

$$W_1 = JW_2 + E \tag{1}$$

All rights reserved. No part of contents of this paper may be reproduced or transmitted in any form or by any means without the written permission of Trans Tech Publications Ltd, www.scientific.net. (#678725360-26/02/25,16:48:29)

In this formula, J is the 3 × 3 orthogonal matrix for compensating the error, E is the residual.

Take the example of measurement for the three-axis acceleration, firstly, fix the system in a cube, secondly, align the frame of axes with edges of the cube, thirdly, put the six tops of the cube down in one horizontal plane, then the six-groups of ideal data-matrix for the acceleration can be achieved as following:

$$a_I = \begin{bmatrix} -g & +g & 0 & 0 & 0 & 0 \\ 0 & 0 & -g & +g & 0 & 0 \\ 0 & 0 & 0 & 0 & -g & +g \end{bmatrix} \quad (2)$$

In this matrix, g is the unit of acceleration of gravity. When the actual acceleration data is:

$$a_R = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \end{bmatrix} \quad (3)$$

With the help of the two matrixes above, by using the least squares method, compensating matrix J can be achieved.

The multi-sensor data fusion

The definition of the coordinate system. The geographic coordinate system and the coordinate system of the vehicle are shown in Figure 1, In this geographic coordinate, the three orthogonal coordinates N, W, T point to north, west and sky respectively; In this vehicle coordinate system, X-axis points to the longitudinal axis front of the vehicle, Y-axis points to the left side of the horizontal axis. Z-axis and both of the X-axis and Y-axis, make up the right-handed orthogonal coordinate system. OXYZ, with respect to the Three corner of ONWT, represent the three attitude angles of the vehicle, ψ, θ, γ which are the heading angle, the pitch angle and the roll angle respectively.

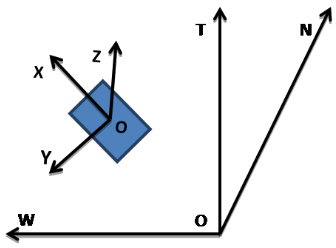


Fig. 1 The geographic coordinate system and the coordinate system of the vehicle

The multi-sensor data fusion for attitude information. In the multi-sensor data fusion, the attitude of the vehicle not only can be expressed by three Euler angles, but also can be expressed by the direction cosine matrix which is called the attitude matrix [3]. In accordance with the rotation sequence of heading-pitch-roll, the direction cosine matrix of geographic coordinates into the vector coordinates can be expressed as :

$$R = \begin{bmatrix} cos\psi cos\theta & cos\theta sin\psi & -sin\theta \\ sin\gamma sin\theta cos\psi - cos\gamma sin\psi & sin\gamma sin\theta sin\psi + cos\psi cos\gamma & sin\gamma cos\theta \\ cos\gamma cos\theta cos\psi + sin\gamma sin\psi & cos\gamma sin\theta sin\psi - sin\psi cos\gamma & cos\gamma cos\theta \end{bmatrix} \quad (4)$$

Differentiation of R :

$$\dot{R} = \Omega(\omega) R \quad (5)$$

$$\Omega(\omega) = \begin{bmatrix} 0 & \omega_z & -\omega_y \\ -\omega_z & 0 & \omega_x \\ \omega_y & -\omega_x & 0 \end{bmatrix} \quad (6)$$

ω_x, ω_y, ω_z is the triaxial angular velocity in the formula.

Then we build the extended Kalman filter equations for the compensation of a multi-sensor data fusion. So we take the first three elements of R-matrix as state variables, and make three-axis acceleration signal as the observed variables. Due to the drift error of gyro signal has a tremendously impact to the precision of attitude solving algorithm, we need to make a real-time estimation for the gyroscope drift error [4]. So that:

$$x = \begin{bmatrix} r_{13} & r_{23} & r_{33} & \Delta\omega_x & \Delta\omega_y & \Delta\omega_z \end{bmatrix}^T \tag{7}$$

$$y = \begin{bmatrix} a_x & a_y & a_z \end{bmatrix}^T \tag{8}$$

The meaning of the characters in the formula can be explained as following: r_{13}, r_{23}, r_{33} are the third column elements of the R-matrix; Δw_x, Δw_y, Δw_z are the drift error of three-axis gyros; a_x, a_y, a_z are the three-axis accelerations, and g is the unit of the gravity acceleration.

After the deduction, the state space model of the extended Kalman filter equation can be expressed as:

$$\begin{cases} \dot{x} = [Ax + v] \\ y = Cx + w \end{cases} \tag{9}$$

$$A = \begin{bmatrix} \Omega(\omega) & \Omega(R) \\ O & O \end{bmatrix} \tag{10}$$

$$\Omega(\omega) = \begin{bmatrix} 0 & \omega_z - \Delta\omega_z & -\omega_y - \Delta\omega_y \\ -(\omega_z - \Delta\omega_z) & 0 & \omega_x - \Delta\omega_x \\ \omega_y - \Delta\omega_y & -(\omega_x - \Delta\omega_x) & 0 \end{bmatrix} \tag{11}$$

$$\Omega(R) = \begin{bmatrix} 0 & -r_{33} & r_{23} \\ r_{33} & 0 & -r_{13} \\ -r_{33} & r_{13} & 0 \end{bmatrix} \tag{12}$$

$$C = [I_{3\times3} \quad O] \tag{13}$$

The meaning of the characters in the formula is explained as following: V is noise vector; w is the process of measurement noise vectors.

By putting the expression (9) discrete and using the Kalman filtering recursive formula to estimating r_{13}, r_{23}, r_{33}, the pitch angle and roll angle can be worked out by using the third column elements of the expression (4). So we will get the attitude information of the vehicle from the multi-sensor data fusion.

Experimental data

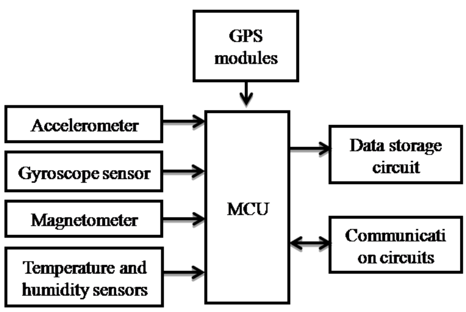


Fig. 2 System hardware architecture

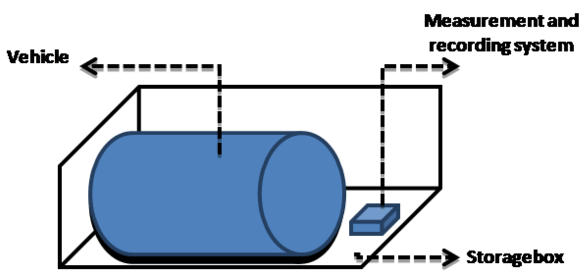


Fig. 3 The installation of the system

So the modular partition of system hardware is shown as Figure 2.The system utilized three single-axis gyroscope sensors (ADIS16100), two double-axis accelerometers (ADIS16209), three-axis magnetometer (HMC5843), the absolute pressure sensor (MPXA4115), the differential pressure sensor (SM5651), a GPS module, and a high-density, non-volatile, high-performance FLASH memory (AT45DB321), the storage capacity is 32Mbit and the read speed is 70ns which can continuously run about 4.5 hours in 5 Hz.

The installation of the system is shown as Figure 3. The vehicle and the measurement and recording system are placed in a storage box. When the physical environment of the storage box is changed, the system can detect the change and then record it. In the experiment, the storage box was transported to the northwest and then shipped to the southwestward before it was returned to the starting point. Through the analysis of the experimental data, the real-time motion information of the vehicle can be achieved by the following diagrammatic curve: （IHD is the practical attitude of the vehicle）.

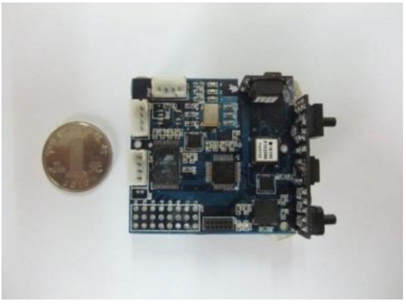


Fig. 4 The physical picture of system

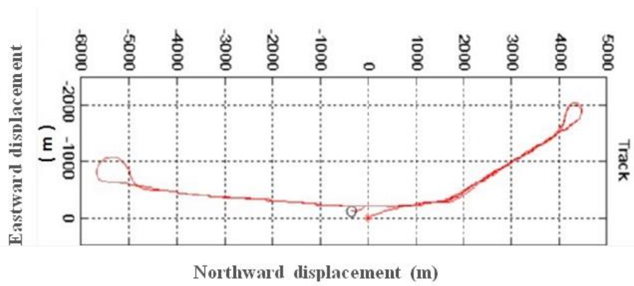
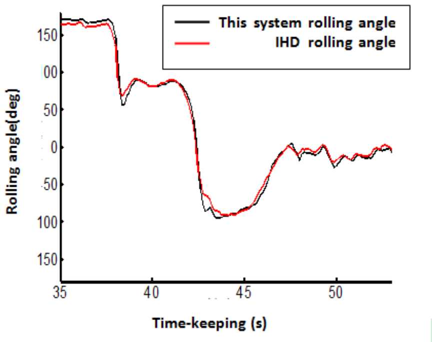


Fig.5 The record data of trace



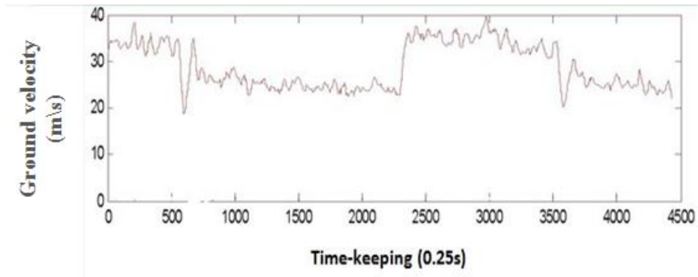


Fig.6 The record data of speed

Fig.7 The record data of rolling angle

Conclusions

This paper presents a method to directly compensate the sensor error for the low-cost MEMS component. This method has improved the accuracy of measurement system tremendously. This system can meet the demands of various tasks of the environmental monitoring and the data acquisition which need to be extremely precise about the degree of accuracy.

References

[1] Erin L R, Walter C, Matthew R. Calibrating a triaxial accelerometer-magnetometer using robotic actuation for sensor reorientation during data collection [J].IEEE Control Systems Magazine,(2005)86-95.

[2] Rong Zhu, Zhaoying Zhou: Optical alignment applied for solving axis-misaligned errors in micro electro-mechanical systems, Int. J. Nonlinear Sciences and Numerical Simulation, (2002) 345–348.

[3] Rong Zhu, Zhaoying Zhou: A Real-Time Articulated Human Motion Tracking Using Tri-Axis Inertial/Magnetic Sensors Package, IEEE Trans. Rehab. Eng., vol.12, no.2, (2004) 295-302.

[4] Rong Zhu, Zhaoying Zhou: The Study of Kinematics in Human Motion Utilizing Integrated MEMS-based Sensors. Proceedings of International Symposium on Test and Measurement, vol.1, (2003)187-190.